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THE SCIENTIFIC MONTHLY

MARCH 1926

THE ORIGIN OF SPECIES, 1859–1925 [1]

By HENRY FAIRFIELD OSBORN

HON. D.SC., YALE UNIVERSITY; RESEARCH PROFESSOR OF ZOOLOGY, COLUMBIA UNIVERSITY

Cuvierian. Cuvier n'est-il pas le plus grand poëte de notre siècle? Lord Byron a bien reproduit par des mots quelques agitations morales; mais notre immortel naturaliste a reconstruit des mondes avec des os blanchis, a rebâti, comme Cadmus, des cités avec des dents, a repeuplé mille forêts de tous les mystères de la zoologie avec quelques fragments de houille, a retrouvé des populations de géants dans le pied d'un mammouth. Ces figures se dressent, grandissent et meublent des régions en harmonie avec leur statures colossales.—Honoré de Balzac: La Peau de Chagrin.

Darwinian. Variation, when we observe it carefully, appears to be aimless. The transmission of acquired characters is unproven, and must certainly be incredibly slow in most cases, if it does occur. We may justifiably adopt the working hypothesis that evolution has been due solely to fortuitous variation and the action of selection on its results. But we must remember that this is still only a working hypothesis. —J. B. S. Haldane: "What does Darwinism amount to?" *The Saturday Review*, Jan. 3, 10, 1925.

Batesonian. The many converging lines of evidence point so clearly to the central fact of the origin of the forms of life by an evolutionary process that we are compelled to accept this deduction, but as to almost all the essential features, whether of cause or mode, by which specific diversity has come to be what we perceive it to be, we have to confess an ignorance nearly total. . . . That particular and essential bit of the theory of evolution which is concerned with the origin and nature of species remains utterly mysterious.—William Bateson, 1921.

The Law of Evolution

The opening of this superb museum, named after its original benefactor, George Peabody, inspired by the monumental labors of Othniel Charles Marsh between 1851 and 1899, filled with Marsh's unique collections and dedicated to the furtherance of research in vertebrate paleontology, marks an epoch in the development of vertebrate paleontology in America.

Led by Thomas Jefferson, at once naturalist and president of the United States, the pioneers of this historic branch of biology worked their way into the then far west of the Ohio River. Beyond, across the Missouri and the Mississippi, stretched the wonderland of the plains and mountains, awaiting the founders of our science, Joseph Leidy (1823–91), Edward Drinker Cope (1840–97) and Othniel Charles Marsh (1831–99). These three paleontologists entered the broad geologic horizons exposed to the eye by millenniums of aridity, far surpassing in richness and content any of the fossil horizons which in the previous century had made Europe the home of the science of paleontology, or the

[1] Delivered at the opening of the new Peabody Museum of Yale University, December 29, 1925. The third of a series of addresses on the origin of species, the first having been "The Origin of Species as revealed by Vertebrate Paleontology" and the second "The Origin of Species, II," presented to the National Academy of Sciences, April 28, 1925, and November 11, 1925, respectively.

Siwaliks of southern Asia as explored by the great Falconer, and only recently challenged in richness by the vast arid stretches of Mongolia, the latest scene of American energy and enterprise in exploration.

Under the uniform environmental stimulus of our virgin Rocky Mountain region nothing could be more divergent than the methods and the life work of these truly great scientists: Leidy, of the German spirit, broad, deep, unassailable in point of fact, the last naturalist to cover life from the Protozoa to Man; Cope, of the Celtic spirit, eager, impetuous, hasty both in observation and in generalization, a genius in classification, natural philosopher of the school of Lamarck, voluminous writer and pamphleteer; Marsh, of the English spirit, a limited writer, deliberate and calculating like Leidy, energetic in discovery and detection of the most significant point in a fossil, glowing with enthusiasm for paleontology, lavish like Cope in personal expenditure, soon surpassing both his rivals in worldwide fame. Aided by Oscar Harger, Marsh was the first to discover and connect up important missing links in the birds, in the horses and in many other chains of vertebrate life so eagerly sought by Darwin and his great proponent Huxley. While eager and fruitful in establishing long lines of descent and new groupings in classification Marsh concerned himself little about philosophy or about the causes and factors of evolution which so constantly occupied the mind of Cope. Endowed with Marsh's talent for seeing and doing the most important thing first, the Peabody Museum, which we now rededicate, became the Mecca for the evolutionists of Europe, and Yale University the most famous center of vertebrate paleontology in the world.

Vertebrate paleontology, from 1847, the date of Leidy's first paper on "The Fossil Horse of America," to 1897–8, the date of Cope's "Syllabus of Lectures on the Vertebrata," through the very diversity of the genius of these three men firmly established the truth of the Lamarck-Darwin theory of evolution.

Thus between 1859, the date of "The Origin of Species," and 1879, *evolution was firmly grounded as a Law of living Nature, and found its place permanently beside the Law of Gravitation of Newton!* In view of the widespread reluctance in America to accept evolution as a law and the tendency to treat it rather as a theory, let us cite Baldwin's definition of "law":

> *Law* (Lat. *lex*, Ger. *Gesetz*, Fr. *loi*, Ital. *legge*): Any formulation of sequences which from demonstration, experimental proof, successful application, or for any other reason, is accepted as having the highest degree of probability. . . . Law is commonly compared with HYPOTHESIS and THEORY just in this, that these latter terms carry less than the highest probability, and are still in waiting for the demonstration, crucial testing, or final observation which, by conferring what amounts to certainty, raises them to the dignity of law.

The Seven Principles observed in the Origin of Species

Not only the law but several of the subsidiary principles of evolution, which from the time of Aristotle (389–322 B. C.) had been conceived and developed in human anatomy, in zoology and in comparative anatomy, became firmly established through repeated verifications in past and present time. These subsidiary principles prove to be universal not only in individual development and experience and in racial evolution and progress but in the social and spiritual life of man. Baldwin thus defines the word "principle" in its bearing on science in general:

> *Principle* (Lat. *principium*, commencement, beginning: trans. of Gr. ἀρχή, beginning, authority): Ger. *Princip;* Fr. *principe;* Ital. *principio.* Scientifically, it is the law through which

a diversity of facts, otherwise unrelated and unexplained, are classified and interpreted: opposed to *datum*, brute fact, or "mere" fact. . . . Greek philosophy began with the search after the principle in the literal sense; that original reality (a) from which other things are derived, and (b) out of which they consist. In the sense (a) it was implicitly or explicitly dynamic, a force, a causal power; in the sense (b) it was static, an element of subsistence. The first meaning led up to Aristotle's form (εἰδος) as a principle; the second to his matter (ὑλη).

Briefly, these subsidiary principles discovered and formulated in zoology as confirmed and amplified in paleontology are five in number: ***First***, the principle of individual adaptation or reaction to changes of motion or function which invariably precede changes of form, as first observed by Aristotle and finally confirmed by the experimental observations of Arbuthnot Lane and Felix Regnault; ***second***, the principle of development through use, of degeneration through disuse, of balance through unchanged or static function. These two principles were understood and expressed by Goethe in the pre-Lamarckian year 1784, when as a brilliant novitiate in human and comparative anatomy he was on the very threshold of evolution:

Thus by the animal's form is its manner of living determined;
Likewise the manner of life affecteth every creature,
Moulding its form.

Third, the principle of Von Baer in embryology and of Hyatt in paleontology of acceleration or the hurrying forward of characters in development and in evolution, and of retardation or the slowing down of characters, according to juvenile or adult needs in the struggle for existence; ***fourth***, the principle of individual and racial struggle for existence and individual and racial survival of the fittest; ***fifth***, the Lamarck-Darwin principle of ébranchement, of divergence, the adaptive radiation of Osborn, permeating the diversity of the plant and animal world. These five great principles, all alike discovered in zoology, were confirmed and ratified in paleontology as the principles of progression and of retrogression, manifested first only in the individual and finally in the race. They are the coefficients both of individual development and of racial evolution, or phylogeny, as set forth in what Osborn has termed tetraplasy and tetrakinesis.

Coefficient. *a.* Cooperating; acting in union to the same end. *n.* That which unites in action with something else to produce a given effect; that which unites its action with the action of another.

But these five coefficients are not all the process, for in the nineteenth century the paleontologists found new fields to conquer wholly beyond the vision of the zoologist; down through the ages he alone became the *camarade intime* of evolution, of the secular forward and backward marching hosts of separate characters, and the new problem presented itself as to how these separate characters arise and conduct themselves. Whereas to the zoologist every minute mechanical part of every animal is still and dead, to the paleontologist every minute part is alive and moving, slowly unfolding in the original sense of the Latin *evolvere* (*evolutio*), just as to the vision of the embryologist individual development is an *unfolding* of the potency of the germ.

Thus the paleontologist discovers two entirely new and additional principles, a sixth and seventh, namely, ***sixth***, the principle of continuity, of continuous and unbroken advance or recession of each character from invisibility into visibility, and, ***seventh***, closely connected therewith, the principle of rectigradation, of the continuous rise of each new organ out of heredity, passing through stages of increasing mechanical perfection, then perhaps gradually subsiding again into the germ-plasm until it finally disappears.

These seven[2] principles which govern the origin of species in mechanical adaptation also concern genetics, for only through paleontology can we clarify our genetical vision of heredity and distinguish the ripples of "saltation" or "mutation" from the waves of "evolution," the local currents and vortices of "variation" from the rise and fall of the tide of great characters. The minute fossilized tissues of the ivory tusks of the mastodon and the stupendous "thundersaurian" *Brontosaurus* displayed in this museum are alike mirrors and "phenotypes" of the evolving germ-plasm out of which they once developed. The stages in the evolution of the horse, camel, mastodon and elephant, in the largest and in the minutest detail, are mirrors of the evolution of the germplasm. If your intellectual tastes incline you to observe the energy of mechanisms within the range of mechanical vision, seek them with Morgan in *Drosophila*, the fruit-fly; if your intellectual predispositions incline you to gaze into paleocrystic mirrors of energy and form, observe the details of ascent from *Eohippus* to *Equus*, of the rise of the Pleistocene mastodon of our forests from the *Palæomastodon* of Oligocene Africa, or the rise of Marsh's giant *Triceratops* from the egg-laying *Protoceratops* of the Desert of Gobi.

Paleontology adds Creation to Evolution

Whether geneticist or paleontologist, you are observing the initial and the terminal phases of a *continuous creative evolution and adaptation of the germplasm*, for paleontology forces upon us this new creational definition and conception of evolution, namely, of a *continuous creative unfolding of life fitted to a continuously changing environment.*

Is it not remarkable that neither through philosophy nor through speculation but through paleontologic research the original Latin word "evolution" becomes inadequate and the old Sanskrit word √ *kar* reasserts itself?

Create (Lat. *creatus*, make, create, akin to Gr. κραίνειν, complete, Skt. √ *kar*, make). I. *trans.* To bring into being; cause to exist; . . . II. *intrans.* To originate; engage in originative action.

Bergson's term "creative evolution" comes nearer expressing the actual truth of the biomechanical aspects of evolution observed throughout a half-century, but it contains teleologic or vitalistic implications which we do not accept.

This new definition is made not to please the still surviving "special creationists" but to express the two new principles of evolution discovered in paleontology, namely, the principle of *continuity* and the principle of *rectigradation*—the one a denial of mutation in biomechanical evolution, the other a denial of fortuity in biomechanical evolution. It is the answer to Haldane (1925) and to Bateson (1921).

Historic Explanations and Interpretations

Before further clarifying these seven zoopaleontological principles let us glance at the historic explanations of evolution, which are as old as philosophic Greek thought (640 B. C.–1600 A. D.); they are all summed up in the great names of Buffon, of Lamarck and of Darwin, who were the first to formulate these historic explanations adumbrated by the ingenious Greeks. Lamarck and Darwin found themselves in an intellectual world very hostile to evolutionism;

[2] This is a concise restatement of Principles I–IX elaborated in "The Origin of Species as revealed by Vertebrate Paleontology," the author's first address on this subject, presented to the National Academy of Sciences April 28, 1925. Printed in full in *Nature*, June 13 and 20, 1925.

they could not put forth the infant evolution theory without an explanation acceptable as in some degree adequate to offset the contemporary creationism; they were alike too eager to explain and were over-reliant on what we now know to be only partial explanations.

The essence of the rival Lamarckian and Darwinian theories can be distilled into modern economic phraseology when we imagine the germ-plasm as our life-capital, for Lamarckism, in economic terms, treats the germ-plasm in this sense. In Lamarck's confident words:

tout ce qui a été acquis, tracé ou changé dans l'organisation des individus, pendant le cours de leur vie, est conservé par la génération et *transmis aux nouveaux individus* qui proviennent de ceux qui ont éprouvé ces changements. [Italics our own.]

In Darwin's original and equally confident statement:

any minute variation in structure, habits, or instincts, adapting that individual better to the new conditions, would tell upon its vigour and health. . . . Those of the offspring who inherited the variation *would have a better chance of surviving*. [Italics our own.]

The germinal capital of Darwin varies in each individual, and the variation which best suits the environment is added to the capital of the survivor. As popularly worded here, these theories of Buffon, Lamarck and Darwin, usually regarded as contradictory, are really complementary; they cooperate, they do not conflict, they are not the whole explanation but only a fraction of the explanation of animal and human progress in evolution.

Yet post-Darwin seekers after explanations and causes came in great waves of opinion and founded schools of followers. Darwin and Wallace strongly condemned Lamarck and presented natural selection so forcefully that it held full sway from 1859 to 1870; then Lamarckism was revived in the minds of Spencer, Cope and even of Darwin himself, until in 1880 Weismann gave Lamarckism in its original form a *coup de grâce* and revived Darwinism in its purest original form. In 1890 Darwinism found a new champion in DeVries, but natural selection appeared under a new name as the "mutation theory"; from 1890 to 1924 this mutation theory enjoyed the following of a great school of mutationists and, in turn, the new support of genetics, until Bateson, founder of the genetic school, declared that *we know neither the cause nor the mode of the origin of species*, and crushed the hopes of mutationists as well as of geneticists to give an acceptable answer to the age-old problem of the origin of species.

Theories of the Origin of Species replaced by Discovery in Paleontology

Meanwhile some paleontologists were speculating while others were quietly devoting themselves to gathering harvest after harvest of facts about the modes and causes of the origin of species. There followed a series of discoveries which put new and unforeseen tests upon the historic theories and explanations.

First, the principles of *phylogeny*, including the actual lines and modes of animal descent, which had been sought in vain by zoology and comparative anatomy, were discovered in one family of mammals after another by intensive research into the minute details of change. Thus in Europe Depéret and Stehlin were ferreting out "ascending and descending mutations" in the sense of Waagen (1869), and in America we were microscoping the four-million-year ancestry of the horses, of the rhinoceroses and titanotheres, finally of the proboscideans, which had been broadly sketched in the telescopic restorations of Leidy, Cope and Marsh. There was revealed a minuteness of realistic detail which may soon be amplified by the still-

sought Tertiary ancestry of man, of which we know the branches and the twigs but not the main trunk.

Second, as a unique result of paleontological research we perceive evolution as a *secular* phenomenon, a process of the ages which, measured either by geology or by the radium content of the rocks, is infinitely longer than either Lamarck or Darwin conceived; Lamarckism in large part holds true as a cause of *secular* evolution, just as Darwinism holds true as a potent cause of secular evolution. On the other hand, paleontology denies absolutely the origin of species according to the original conceptions and literal interpretations of either Lamarck or Darwin. In claiming that all that is acquired is transmitted Lamarck was overconfident, as Darwin was overconfident in claiming that every variation, however slight, favors the chance of survival.

Third, the grand result of paleontological research was to transfer, from the field of reason, imagination and speculation, to the field of direct observation the whole question of the modes and methods of evolution and the whole problem of the manner in which new specific adaptations originate and of the details by which new biomechanical species are constantly created. I refer to such biomechanical adaptation as the elongated neck of the giraffe, the classic case cited by Lamarck and Darwin.

In this and many other examples it appears that "species" and "adaptations" are practically synonymous terms, as may be clearly seen in the history of these two terms, from Aristotle to Linnæus. The origin of species and the origin of adaptations are of the same significance, for every "species" is an ensemble of countless adaptations in various stages of rise and decline. What Aristotle 300 B. C. called an adaptation, Linnæus in 1758 called a species. When Aristotle in his "History of Animals" and in his "Physics" debated the natural causes of adaptations he had in mind the same structures and functions as those which Linnæus used in defining his species. For example, the celebrated "survival of the fittest" passage in Aristotle's "Physics":

> What, then, hinders but that the parts in Nature may also thus arise? For instance, that the teeth should arise from necessity, the front teeth sharp and adapted to divide the food, the grinders broad and adapted to breaking the food into pieces. . . . It is argued that where all things happened as if they were made for some purpose, being aptly united by chance, these were preserved, but such as were not aptly made, these were lost and still perish, according to what Empedocles says concerning the bull species with human heads. . . . Nature produces those things which, being continually moved by a certain principle contained in themselves, arrive at a certain end.

For example, again, Linnæus (1758) defines the anthropoid ape known as the orang:

> *Simia: Dentes Primores* IV, approximati.
> *Laniarii* solitarii, longiores hinc remoti.
> *Molares* obtusi.
> *Cauda nulla:* Simiae *veterum.*

To resume the bearing of paleontology on explanation and interpretation, from the very dawn of human ambition to observe and interpret nature there have been only two broad solutions to the problem of adaptation and of the origin of species: the supernatural and the natural. Aristotle adopted the natural and fully debated the essential idea of both Darwinism and Lamarckism; to Aristotle's formulation of Lamarckism Brooks (1899) has called our attention:

> Herbert Spencer tells us that the segmentation of the backbone is *the inherited effect of fractures, caused by bending,* but Aristotle has shown ("Parts of Animals," I. i.) that Empedocles and the ancient writers err in teaching that *the bendings to which the backbone has been subjected are the cause of its joints,* since the thing to be accounted for is not the presence of joints, but the fitness of the joints for the needs of their possessor. [Italics our own.]

Since 1859 there have been hosts of explanations and hypotheses overworked by various schools of opinion. Darwin's word "variation" has been a will-o'-the-wisp leading biologists into many morasses, with its many modern mutant terms, "variation," "selection," "mutation." Paleontology enables us to winnow out the wheat from the chaff in all these partial explanations of the origin of species, for it demonstrates that hosts of variations such as those set forth by Bateson in the year 1894 in his "Materials for the Study of Variation" are wholly insignificant in the evolution process.

In our natural tendency to follow the line of least resistance and to seek explanations and *causes before facts,* may we not guard the advice of Pliny as quoted by Fourtau:

> Pline l'a dit, et on ne saurait trop le répéter; il convient d'abord de bien exprimer ce qui est, avant de remonter aux causes: *Quærere tu causas, mihi abunde est si expressi quod efficitur.* Je m'estimerais très heureux, si, dans ce travail, j'ai réalisé le sage précepte du naturaliste romain.

The facts of paleontology throw a new and critical light on the relative value of the three historic explanations as to the causes of adaptation, namely, those of Buffon's direct action of environment, of Lamarck, and of Darwin, which alike turn on the question of inheritance or transmission of individual adaptation. Paleontology cuts like a two-edged sword on any theory of immediate action.

First, inasmuch as marvels of origin are due to individual adaptation, which may by inheritance furnish the key to evolution, the idea running through the minds of Aristotle, Lamarck, Spencer and Cope is shown by paleontology to be illusory, for individual adaptation now proves to be a *secular* rather than immediate cause of the origin of species as Lamarck suggests. Even if we were to demonstrate the immediate, prompt and entire inheritance imagined by Lamarck, the majority of new biomechanical adaptations observed in paleontology would still remain wholly unaccounted for.

Second, there is the historic idea of Buffon as to the inheritance of the direct action of new environment; it is true that new species, as they are observed by systematists, suddenly or gradually originate in this way, as shown by Crampton in *Partula,* because in the laboratories of nature the new environment endures. The "species" of the systematist is not the same as the "species" of the geneticist, but nature does not make this distinction. A host of field naturalists have long since proved Buffon's principle to be very general among birds and mammals. Another host of experimentalists in America, England and Germany are demonstrating the immediate origin of new species in *le monde ambiant* of chemical and physical experiment. So far as we see at present such origin of the species of systematists is chiefly in biochemical adaptations in which the germ may be affected permanently by a molecular or atomic saltation. On the contrary, from the secular point of view of paleontology the germ-plasm or *keimplasma* of Weismann is at once the most stable and the most plastic element in life; it offers stubborn resistance to both Lamarckian and Buffonian influences, such as we observe day by day in nature and in the laboratory.

On the affirmative side paleontology proves that in the long run of geologic or secular time both Buffon and Lamarck, as well as Darwin, were right in their main conceptions: organs starved by unfriendly environment finally disappear; organs which do not pay their way and are starved by disuse slowly drop out of the germ-plasm; vitally essential organs are either absolutely stable or progressive. Why not therefore concede the truth of the great

conceptions of Buffon and Lamarck, even if immediate inheritance by the germ is disproved in the great majority of cases? Why not concede the still greater conception of Darwin, misled as he was as to time by the marvelously rapid evolution of the germ-plasm witnessed in artificial selection? Whereas neo-Darwinians have been as impatient as neo-Lamarckians in looking for instantaneous results in the first or the few following generations, paleontology proves that the deferred secular action of natural selection is as firmly established as the deferred secular action of both the Buffon and the Lamarck factors. Both in progressive and retrogressive organs paleontology proves that every organ needs the sustaining and standardizing power of selection as it acts to-day in swarms of a trillion mosquitoes, in herds of a million bison, in flocks of a thousand ducks.

Rectigradations and Continuity await a New Conception

But if we grant that Buffonian, Lamarckian and Darwinian factors were all true even in this secular sense, if we grant that the living and the lifeless environment, the adaptation, habit and survival-of-the-fittest variations combine continuously to produce new adaptations and species, do we then account for all we paleontologists observe in the modes of origin of species in ascending and descending phyla of all the animals we have been able to study?

We answer, "Certainly not." Buffonism, Lamarckism and Darwinism combined would account for only a small fraction of what we observe.

The unaccounted residue of creative evolution is by far the larger—is, in fact, infinitely the larger—part. Here is the critical point in modern biology where we pass from the rational, *i.e.*, all that is within the range of observation, experience and reason, to the superrational, namely, to the ultimate unknown causes of what Lucretius called "the firm and undeviating order," when he quoted his master Aristotle in his famous refutation of Democritean fortuity in nature:

> Order and a firm and certain constitution or being are far more obvious in celestial natures than in us, but an uncertain, inconstant, and fortuitous condition is rather the property of the mortal race.

This discovery of the "firm and undeviating order" in the origin of species with which paleontology replaces all the chance explanations of adaptation from Empedocles to Darwin is the supreme service which paleontological research renders to biology. It is into this new and mysterious field, into this new teleology that the paleontologist of the future may venture. Perhaps within the very walls of the Peabody Museum, where adaptation is set forth so transparently by the master hand of Lull, some young Aristotle or Darwin may find his inspiration to grasp the problem of the origin of species which has baffled man for two thousand five hundred and eighty-five years.

Are we right in concluding with Balzac in his brilliant *éloge* to Cuvier that paleontology comes very close to philosophy, the science of the causes and origins of things? Was the author of *La Peau de Chagrin* right in his prophetic vision of the then infant science, the *paléontologie* named by Cuvier?

> Il réveille le néant sans prononcer des paroles artificiellement magiques; il fouille une parcelle de gypse, y aperçoit une empreinte, et vous crie: "Voyez!" Soudain les marbres s'animalisent, la mort se vivifie, le monde se déroule! Après d'innombrables dynasties de créatures gigantesques, après des races de poissons et des clans de mollusques, arrive enfin le genre humain, produit dégénéré d'un type grandiose, brisé peut-être par le Créateur.

CHANGING LEVELS OF THE GREAT LAKES

By Professor HERMAN L. FAIRCHILD
UNIVERSITY OF ROCHESTER

THE present very low levels of our "Unsalted Seas" and the effect of the diversion at Chicago of Lake Michigan water to Mississippian drainage is of scientific and economic interest to the public, and will remain a matter of lively interest and dispute until the hydraulic and commercial questions are adjudicated. A brief review of the scientific elements and of the engineering data is pertinent.

The subject is one of considerable complexity. The natural changes in the height of the water surfaces involve several factors, in meteorology, hydrography, physiography and geology. And when we have interference with the natural flow by changes in the outlets, and especially by new, artificial outlets, there is added the interesting element of hydraulic engineering. And with these comes the stress of commercial rivalry between great cities and large sections of the continent.

The charts of the United States Lake Survey (Detroit, Michigan) show graphically the eccentric and striking changes in level of the five lakes since 1860, or for the last sixty-five years. Beyond the quite regular annual fluctuation of high water in summer and low in winter, usually about one foot, there is no regularity or clear periodicity. The greater changes of level through several, or many, years are certainly due to meteorologic or climatic conditions. These fluctuations are so variable and so unlike in the different lakes that it is not practicable to make predictions of unusual changes.

In study of the scientific data relating to the lake levels a single lake should first be taken as an independent waterbody or without any influence from tributary lakes. Lake Superior may be an example. The dominant factors of weather and land surfaces are varied and interrelated. Water is added to the lake only by precipitation, rain or snow, over the drainage basin. Such supply may be directly into the lake or indirectly by the inflowing streams. The whole supply varies greatly in time of year and from one year to another, according to the variable climatic conditions of our middle latitudes. To the extent that the precipitation is snow the run-off from the land awaits the uncertain melting, which may all occur in the spring. And this supply from the land drainage will also vary in time according to the condition of the ground. If the soil is receptive, like a forest area or a tilled surface, the water is partially retained for gradual release. If the slopes are steep and bare or the ground is saturated or is frozen the run-off is prompt. Frozen streams and ice-jams have an opposite effect. Moreover, these factors may vary in different years, or every year, between the several drainage areas of the lake, according to latitude, the topography or surface slopes and the soil characters. In the case of the Great Lakes the time of the winter and spring run-off and its volume may be very different on the Canadian side of the basin from that on the south side.

Removal of the water is not only by the visible overflow through the outlet but largely by the invisible evaporation. This is the most variable and the critical factor. Over the Ontario basin it is estimated that one half of the precipitation

is carried away by the air, as the "fly-off." This depends, of course, on the variable elements of the weather, as temperature, sunshine and humidity. A dry, warm and clear summer will rapidly lower the lake surface, while a cold, cloudy, wet and humid season will effectively inhibit evaporation. In a large basin, like that of any one of the Great Lakes, these meteorologic conditions may be unlike in different parts of the area, even during the same season.

One element in the hydraulics of the single lake tends to check extremes in the surface levels. Higher surface of the lake increases the velocity of flow in the outlet, and the faster outflow tends to lower the surface level, while a low level of the lake has opposite effect. But this element is not important and is greatly overbalanced by other factors.

For an independent lake with no human interference it is evident that any considerable variation in the surface elevation is an effect of the complex and variable atmospheric conditions along with the characters of the land of the drainage area. One important factor, elusive and unmeasured, is evaporation.

Now, when we have to consider a chain of lakes, it is evident that any lake is subject not only to its own variables but also to those of all other lakes which are tributary to it. The Michigan-Huron body has the added variant of the great Superior. Lake Erie feels the changes in the three upper and larger lakes. And Lake Ontario, with the smallest area, is subjected to the total net vicissitudes of all the lakes.

As the Great Lakes collect from a large drainage territory, which commonly has quite different weather and stream conditions, it appears that excesses in some areas may be more or less balanced by contrary effects in other areas. Such moderating factor applies especially to Erie and Ontario.

Some causes of temporary, but sometimes sudden and surprising, changes of water level should be described. Strong and steady winds may sweep the water from the windward to the lee side of a lake so as to produce great differences of level. In Lake Erie such difference is said to have been twelve feet, and, aided by the damming effect of ice, with northeast winds, have left Niagara Falls practically dry. Occasionally a sudden and decided change of water level along shore is puzzling and mysterious to the people and causes wild speculation. These quick changes in calm conditions are produced by passage across the lake of atmospheric waves of different pressures. A decided low-pressure area or whirl, cyclonic in nature and perhaps tornadic in intensity, may so lower the atmospheric pressure beneath it as to produce a rise or bulging of the water surface. The greater pressure in the surrounding area pushes the water in from all sides. A barometric "low" or cyclonic whirl of not uncommon intensity might cause a diminution of pressure equal to one half inch of the mercury column; and this implies a decrease of weight of one half million tons on a square mile. On the shore the first effect is usually the mysterious withdrawal of the water, followed by a "sea wave," and later a succession of dying-out waves. Such changes of level, due to the passage of atmospheric highs and lows, are called "seiches." Minor fluctuations of this nature are frequent, and large lakes in middle latitudes are rarely at rest for any considerable time.

The Great Lakes are also affected by the lunar tides, but these are so weak that they are masked by the seiches and wind currents.

Human Interference

Thus far reference has been only to the agencies and processes of nature.

But these are seriously modified by human occupation of lands surrounding the lakes, resulting in deforestation, soil cultivation and damming of streams. Contrary to popular belief deforestation has little effect on precipitation, which is dependent on conditions in the higher atmosphere. But removal of the forest cover is effectively injurious by increasing the rapidity and amount of the flood run-off, especially on steep and bare slopes. Agriculture has the opposite effect, by producing porosity of the soil, thus holding back the precipitation and increasing the evaporation. Damming of streams and production of ponds or reservoirs has some effect in reducing flow into the lake, by increasing the surface for evaporation. Use of water for irrigation effectively reduces the inflow by increasing evaporation; but this is negligible in the Great Lakes region. Extension of farming has undoubtedly reduced the flow of streams into the lakes; and the total effect of human occupation of the basin of the Great Lakes has been a permanent lowering of the lakes. This may explain, at least in part, the general fall of the lakes during forty years. The steady drop during the last six years, amounting to over two feet, must be blamed on the weather, as described below. Changes of climate through long periods are recognized, but they are much slower in effect than the measured changes in the lakes.

The Geologic Element

Natural geologic processes are responsible for both the production and destruction of all lakes. Ponded water, or lakes, is not a normal feature of natural drainage. Streams do not make lakes. Created in any manner lakes are short-lived and evanescent features, measured in geologic time. Before the Glacial Period, which was only yesterday, speaking geologically, there were few, if any, lakes in North America. There are no lakes to-day in the southern states outside of Florida. The ox-bow lakelets in river floodplains are not in the same category. The scores of thousands of lakes and tarns in the glaciated territory of the northern states are due to the blocking of stream courses by glacial drift. In time they must disappear, if nature were left alone.

Lakes are extinguished by the down-cutting of their outlets and by the filling of their basins. The latter is done by inwash of detritus, sand, clay and lime, and by vegetal growth. The operation is usually slow but certain. We see some rapid work of filling in the many abandoned mill sites on our streams. The extensive plains at the heads of many lakes, as the Finger Lakes of central New York, are excellent examples of recent lake filling, by the inwash of the inlet streams. The Great Lakes, with the possible exception of Superior, came into recent existence as an effect of the work of continental glaciers. Their life has been too short, only scores of thousands of years, for the destructive processes, down-draining and filling, to be visible.

One geologic force has had great effect on the levels of these young lakes. The normal level of a lake is determined, it is evident, by the attitude or elevation of its point of overflow, or outlet. Since the lakes were formed their outlets have shifted in vertical relation to the basins, due to the tilting uplift of the glaciated territory. The area had been depressed by the weight of the ice caps, which were perhaps two miles in depth. With the removal of the weight the land has risen, probably recovering only a part of its original elevation. In the states and in southern Canada the land rise has been a slanting uplift, being on the south side of the doming. For example, at Rochester, New York, the post-glacial uplift is 250 feet. On the north boundary of New York the rise has been 740 feet, and in

southern Quebec something over 1,000 feet.

Lake Ontario was initiated at sea level. It was the immediate successor of Gilbert Gulf, which occupied the Ontario basin and was confluent with the sea through the Champlain-Hudson estuary. By the tilting rise of the land, following the melting of the Quebec ice sheet, the district of the Thousand Islands was raised out of water, forming a barrier in the St. Lawrence Valley. The water imprisoned behind this dam became the Lake Ontario, and its elevation has risen from zero to 246 feet by the rise of its outlet. Lake Ontario is the latest great physiographic feature in America, with a life history of perhaps 10,000 years.

It is possible that Lake Superior was originated by a down-warping, or basining, of the earth's surface. But the other Great Lakes as we now see them are doubtless the indirect effect of glaciation. Their basins were portions of great river valleys, carved during the millions of years of preglacial time. The basins were not cut by glacial erosion but have been formed by accumulation of glacial drift in sections of the old valleys; the basins being the unfilled portions. The courses of the ancient streams have been mostly obliterated. By the rise and deformation of the land the lake basins have been tilted and deepened.

The question now arises: Are the lake levels now changing because of continued uptilting of the region? The reply is quite confidently in the negative. Remeasurement of the Lake Survey benches, established fifty years ago, shows no more change than may be attributed to settling of structures and errors of measurement. Any continued tilting uplift would raise the level of Ontario, because its outlet is on the north. This would produce flooding of the south shore. In less degree the same change would affect Erie. But northward uptilting would lower the north shore of Huron, while raising the south end of Michigan. Such changes have not been proven. Either the land movement is too slow to produce visible effects in nearly a century, or it has practically ceased in the region of lakes.

The natural downcutting of outlets in hard rocks is a very slow process, and in the case of the Great Lakes it is a negligible factor in this study.

It has been questioned if the recession of the falls of Niagara might possibly so enliven the flow of the rapids as to have some backwater effect on the level of Erie. This appears extremely improbable. It is admitted that in the geologic future the recession of Niagara Falls may drain Lake Erie.

Comparison of Levels

Thus far our discussion has mostly been on the philosophy of changes in lake levels. Let us now apply the theory to the facts.

Complaints of extremely low water in all the lakes have become both frequent and emphatic. This is confirmed by the gauges and published charts of the U. S. Lake Survey. For the past six years there has been a steady drop in all the lakes, even in Superior. The older record also shows that there has been a general average fall of two feet or over from the levels of many years ago. The graphs of the Survey charts give the details. This lowering of water surfaces and shallowing of depths seriously interferes with the great volume of shipping, and has great commercial, economic and international importance.

Lake Superior, independent of the other lakes and unaffected by the Chicago diversion, has participated in the recent fall, having dropped one foot to 600.8 feet above ocean in March of last year. And this drop is in spite of some control at the outlet. However, it was

as low as that in the springs of 1871 and 1880 and was lower in 1911.

Michigan and Huron were high in the summers of 1917, 1918, being up to 582 feet, A. T., and have been dropping since to 578.23 feet, in January and February of last year, the lowest in their record.

Erie fell in February of last year to its lowest record, 570.46 feet.

Ontario dropped to 244.22 last January. But it was lower in 1895–96, reaching its minimum of 243.41 feet. All the lakes except Superior were low in 1895–1896.

The blame for the present low water has been placed, by many people and newspapers, on the diversion by the Chicago drainage and ship canal. This artificial waterway was opened in 1900, to carry water of Lake Michigan, with the diluted city sewage, over into Mississippian drainage. The canal is designed to carry 10,000 cubic feet per second. The U. S. War Department permitted a diversion of 4,167 c.f.s. and in 1913 sought an injunction to prevent more than that amount. In 1923 the Federal Court granted the injunction, and on appeal to the U. S. Supreme Court the injunction was upheld by decision given in January of last year. The War Department is allowing time for adjustment.

On request of the trustees of the Chicago Sanitary District a board of review, composed of twenty-eight eminent hydraulic and sanitary engineers have reported on some phases of the complex problem. The board finds that the diversion for several years of about 10,000 c.f.s. has caused a lowering in Michigan-Huron of five inches; and a reduction in the flow of Niagara of 5 per cent. Of course this is relatively a small amount when compared with the two to five feet variations of levels. However, it must be admitted that it is a continuous and constant factor in the lowering of the lake levels, and especially effective and hurtful in time of very low water, as at present.

Some part of the fall in Michigan-Huron is attributed to the recent enlarging of its outlet, the St. Clair River, and to the temporary storage in Lake Superior.

There is diversion from Lake Erie by the Welland Canal, the Black Rock Canal and the N. Y. State Barge Canal. This, it is estimated, has lowered the lake four inches. But this diverted flow finds its way into Lake Ontario. The Chicago diversion is the only one that affects the four lakes.

Meteorologic Factor

The annual reports of the U. S. Weather Bureau show that since 1919 (report for 1924 not yet available) the weather was warmer than normal in all the states that border on the Great Lakes, except New York. Also that the precipitation was in general below normal. The higher temperature implies greater evaporation. These facts appear sufficient to account for the acute fall of levels during the last six years. It may be expected that this low stage is not permanent, but will soon be followed by rising levels.

The more permanent average lower levels of later decades, of some two feet, may reasonably be attributed to increasing human occupation and extended agriculture, which has accelerated the critical factor of evaporation. The change in the lake levels is too rapid even in the past fifty years to be an effect of any long-period and universal variation of world climate.

The conclusion appears unavoidable that the present very low levels of the lakes, which is not unprecedented, are not due to any geologic nor physiographic change of the region, nor in any

considerable degree to enlarging of outlets. And it may be admitted that only minor effect can be placed on the diversion at Chicago. The chief cause is certainly meteorologic. It lies in some slight and indeterminate shifting of the great atmospheric currents which flow eastward, at high altitudes, across our latitude; along with erratic behavior of the whirls or cyclones which are responsible for our "weather."

Engineering Data

The Chicago Sanitary District is building an elaborate and expensive system of sewage disposal plants. But the engineering Board of Review recommends that the present diversion by the Chicago Canal should be permitted in continuity; for three reasons: First, that the topographic and physical conditions of the city are of such character that without this flow the flooded streams and storm-water would carry part of the sewage into Lake Michigan; second, that the full canal is desirable for the "Gulf to Lakes" commerce; third, that with easily constructed regulating dams at the outlets of the lower lakes the Chicago diversion will be negligible.

The analysis by the Board of Review of the lowering in Michigan-Huron is interesting as a study in hydraulics. The fall of thirty-one inches is apportioned as follows:

Excessive evaporation and subnormal precipitation	13	inches
Increased flow by the enlarged St. Clair River	8	"
Diversion at Chicago	5	"
Storage and retention in Lake Superior	3	"
Back-water effect by diversion and lowering in Erie	2	"

Chicago has offered to bear the cost of regulating works to control the outflow at Niagara and St. Lawrence, the dams or locks to be designed and built by the U. S. Engineers. Lake Superior outlet has been under partial control for eight years. Such regulation should certainly be extended to all the lakes, regardless of diversion at Chicago or elsewhere. This control would conserve the high waters which now escape and would permanently raise the levels of all the lakes for deeper-draft ships and safer navigation. The dam built by Canada at the Galop Rapids has lifted the level of Ontario six inches.

It is recognized that economic rivalry of the great cities and the conflicting interests of existing and proposed routes of commerce are intent on controlling public opinion and political action. But it should be realized that future commerce will need all the water routes that are possible and that nature will supply sufficient water if it is intelligently conserved.

In the issue of this journal for December, 1924, is a masterly and very interesting article on the hydraulics of the Great Lakes and on their proper control, by the lamented Dr. John F. Hayford; entitled "The best use of the Great Lakes."[1]

The Glacial Warren River

The path of the Chicago Drainage Canal has special geologic interest, because the city has merely utilized the path of a great river of Glacial time.

When the latest ice sheet was waning there was an episode, perhaps some thousand years, when much of the Great Lakes area was exposed to the air, but while the ice sheet yet blocked the two lowest passes for water escape. These are the eastward passes by the Mohawk and the St. Lawrence valleys. The overflow of the copious glacial waters was then forced south by two passes, one through Ft. Wayne, Indiana, to the

[1] The Scientific Monthly, Volume 19, 1924, pages 585–597.

Wabash Valley, the other through Chicago to the Desplaines-Illinois valley. Both courses led to the Mississippi. At length the Chicago outlet robbed the Ft. Wayne outlet and for a long time it carried all the outflow of the Great Lakes area, including western and central New York. This great outlet river, which flowed through the site of Chicago, is called Warren River, after General G. K. Warren, U. S. Engineers, who recognized the splendid channel as the work of a great river, without knowing its history. Deepening this old scourway only a few feet permitted Lake Michigan to outflow again to the Mississippi. The glacial lake which lay in the Michigan Valley and was drained by the Warren River is called Lake Chicago. The lake in the Huron-Erie-Ontario area, which has left good beaches in New York, is also called Lake Warren. Its outflow was across the state of Michigan into Lake Chicago. So the glacial waters of New York helped to carve the low channel at Chicago and ultimately to provide some relief for the great city with the poor location.

The Chicago glacial outlet was abandoned when the receding front of the ice sheet permitted the imprisoned waters to escape eastward to the Mohawk and Hudson valleys, and later by the present flow through the St. Lawrence.

FOSSIL HUNTING IN THE WHITE RIVER BADLANDS

By WILLIAM DRUMM JOHNSTON, Jr.

UNIVERSITY OF CINCINNATI

MAN has retained ontogeneric memories of his first livelihood; of a weary watch by the salt lick, a patient stalk up wind, a spring, a struggle and then the perfect contentment. A full stomach, I can not deny, was the consummation of his labors, but beyond such a homely stimulus as hunger there was something else—the joy of the hunt, a pure emotion, undefiled by cravings of the flesh.

As a child, I have heard my father recount his experiences in a day's shooting, and wondered at the enthusiasm which resulted from so depressing an occupation as spending a cramping day in a damp blind, to be rewarded with only a brace of ducks at nightfall. Later, I wondered at the enthusiasm of a little friend who succeeded in snapping the picture of a red-winged blackbird on its nest of reeds. On one of those boring picnics which are so dear to us, I have watched a painstaking search for four-leaf clovers drag through the afternoon, and with each new manifestation of zealousness in the hunt, I met ardor with apathy, or, at best, with a polite interest. I fear that I scoffed at my hunting friends, and in just retribution, the hunting instinct, which hitherto had reposed with proper decorum in the limbo of my unawakened racial memories, shook itself, yawned once or twice and strode into my consciousness.

With a pick closely akin to those which are used for ice work in mountain climbing, a whisk broom of homely simplicity, a few pointed implements of nondescript character which, to the uninitiated, might pass as a collection of carbon-cleaning tools, I was equipped for the pursuit of the animals which ranged during Tertiary times, some three million years ago, over what is now the White River Badlands, in the corner where South Dakota, Nebraska and Wyoming touch.

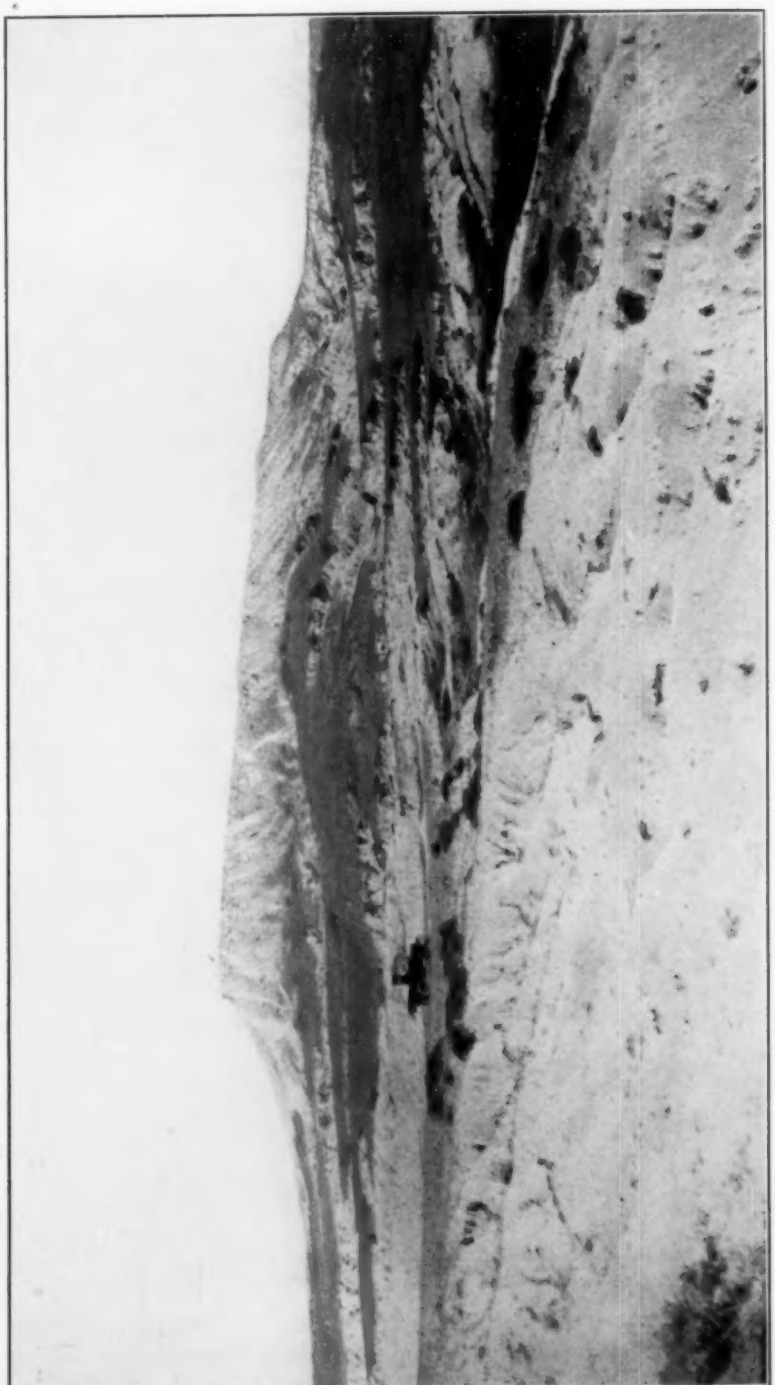
Paul Christian Miller, of Walker Museum, the University of Chicago, and I journeyed from Chicago to Harrison in a Ford car equipped with a light truck body, and established a base from which to make our collections at the foot of Pine Ridge in Sioux County, Nebraska, at the edge of the Badlands.

The White River Badlands, or the *Mauvaises Terres* of the early French-Canadian trappers, lie to the south of the Black Hills, extending into Wyoming on the west and thence east through Sioux, Dawes and Sheridan Counties in Nebraska. To this region the name "Badlands" has applied, not because the country is without economic value, for its grassy stretches support many ranches, but because of the difficulty experienced by early travelers in traversing its labyrinthine gullies and unassailable slopes. Water, too, in much of the region is alkaline and unfit for drinking purposes.

The intricacy of the erosion pattern is an ever-perplexing fact. Tortuous channels, usually dry, wind their serpentine course between steep ridges, and gullies heading in all directions add to the confusion of the landscape, a picture without vegetation save on the undissected

TORTUOUS CHANNELS

WIND THEIR SERPENTINE COURSE BETWEEN STEEP RIDGES.



YEAR BY YEAR THE BADLANDS CUT INTO THE GRASSLAND

flats, where each rainfall leaves its scar on the bare, varicolored walls of the non-resistant clay. To the south Pine Ridge marks the horizon with its pine and cedar-covered slopes, and far to the north in the blue gray distance loom the Black Hills. Between are the Badlands.

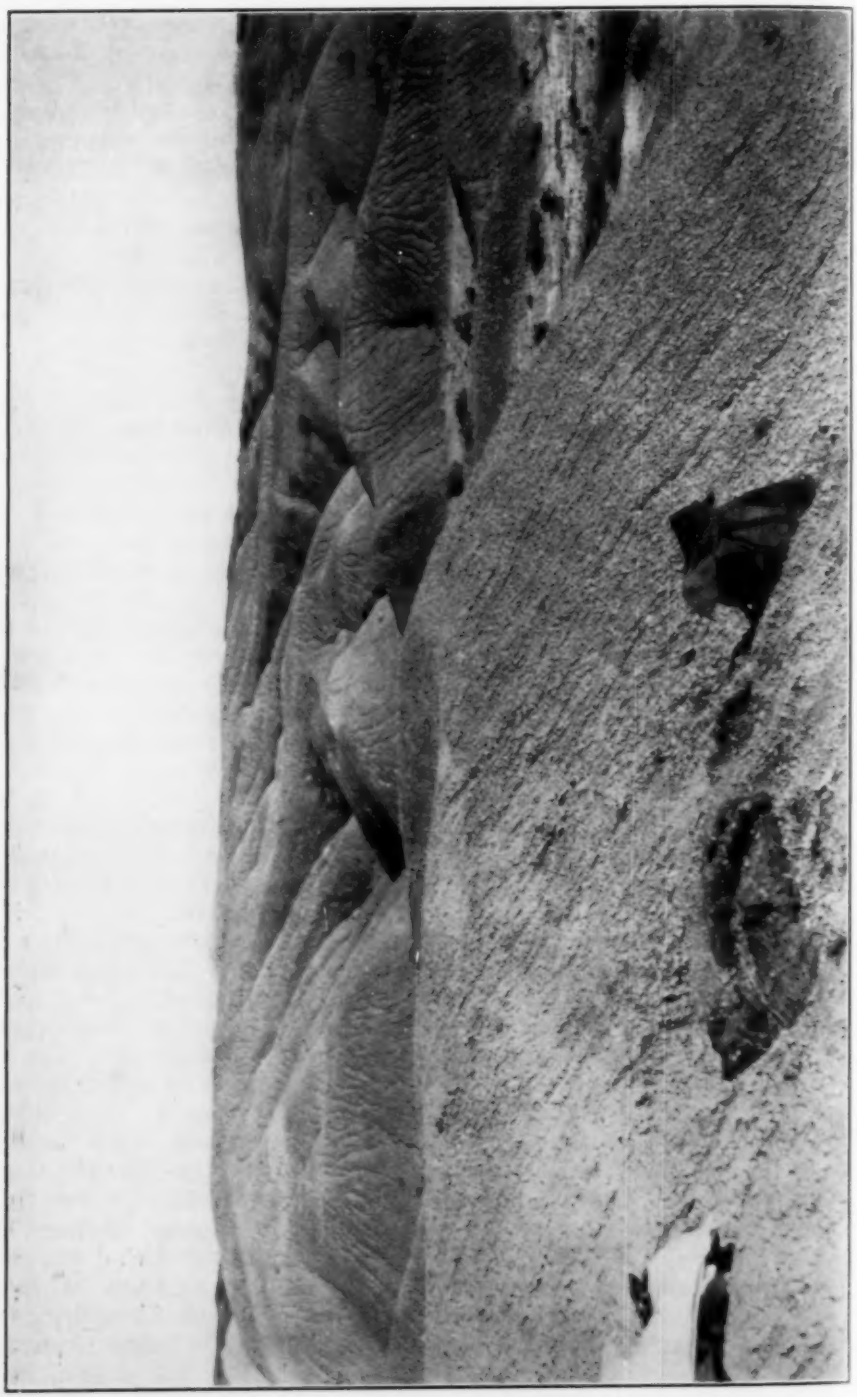
Within the barren area conditions are most favorable for the fossil hunter. The absence of masking vegetation renders visible each bit of bone as it was exposed by the last rain. Here is the ever-present *Oreodon*, a beast combining the characters of camel, deer and pig, and occasionally a fragment of *Dinictis*, the first of the saber-tooth tigers. *Titanotherium*, the giant of the times, roamed the plains during the Oligocene and their ponderous skulls are brought to the surface by the unceasing excavation of running water. It is the occasional rain and the melting snows which make it possible to collect a new crop of bones from the same area every decade, for the fossil hunter only digs where a bit of bone shows at the surface and passes over what he can not see.

As with other sports, fossil hunting has its own technique, but, unlike many, a fair degree of facility comes with the first few days of practice.

Comfortably established near a ranch house with our tent set up in one of the rare groves of trees, our first chase began in the cool of the early morning. I was a novice at the sport, having passed my first few years of fossil hunting in a country of early Paleozoic rocks which were deposited when the fishes were the only vertebrates, long before the beginnings of mammalian life upon the earth. Miller, however, was a veteran. His early years he had spent with the American Museum of Natural History, collecting dinosaurs at Bone Cabin quarry in Wyoming, a classic hunting ground so named because a shepherd's cabin whose walls were built of massive dinosaur vertebrae first attracted the attention of paleontologists to the wealth of fossil material in the surrounding slopes; he had searched the Bridger Basin in Wyoming for remains of Eocene primates, and for many years he had roamed the hillsides of northwestern Texas in company with the late Dr. Samuel W. Williston in quest of the Permian fossils which have made Walker Museum the repository of the richest collection of early amphibians and reptiles in the world. With such tutelage, the fundamentals of fossil hunting were easily mastered.

The ranch at which we were camped nestled under the protection of Pine Ridge and was enclosed upon three sides by the Badlands. Our first morning's sport was characteristic of many days to follow. With pack sacks slung over our shoulders and picks in hand, we wandered through the maze of gullies, stopping here and there to prod about a bit of bone peeking through the clay of the ravine wall. Usually the bone was a bit of rib, or a fragment of turtle shell, partly replaced by mineral matter from the percolation of ground water through the clay, but seldom was it replaced to the extent of being "petrified." A few blows with the pick sufficed to show that the fragment was useless, and we pushed on to where the next bit showed itself. So the morning passed.

It was late that afternoon when we made our first find. Miller had stopped to examine a patch of white, barely showing through the cover of greenish clay. I watched him prod about it with his trowel. Little by little he dug the clay away, and with each trowelful the whitish area increased. In a few minutes he had exposed enough to be able to tell me what he had found, the pelvis of a *Titanothere*, a mammal of almost elephantine proportions which disappeared from the earth long ages ago. When the last of the clay cover had been dug away, Miller brushed the bones clean and marked the spot with a piece of news-



THE CHADRON BADLANDS
IN THE FOREGROUND IS A TITANOTHERIUM PELVIS.

paper weighted down with a stone on the nearest ridge. Later, when we would begin our collecting, we could find our prospects by searching the ridges for markers.

During the next few days our finds mounted apace. Miller had an uncanny knack for seeing each bit of bone and for recognizing those which were worth investigating, while I, at first, passed over bone after bone, only to have them brought to my attention with good-humored raillery over the blindness of the city-bred. Before the first week had passed, however, my observation was more acute, and, when early in the second week, I found our first skull of *Dinictis*, one of the early, saber-tooth tigers, I preached my prowess as a fossil hunter from the hilltops.

By the middle of the second week, we had staked claim to several dozen skulls and a goodly assortment of skeletal remains of a great variety of beasts—*Leptomeryx*, the diminutive deer; *Mesohippus*, one of the three-toed horses, and *Hyracodon*, a member of the rhinoceros family. Then collecting began in earnest. Armed with a bucket of sour flour paste, thin shellac and strips of burlap, we sought the bones which we had previously marked.

Among our first finds was a *Titanothere* skull, a massive affair, the size and approximate shape of a Texas saddle. It was upright in the clay, with only the top exposed just as Miller had cleaned around it on our prospecting trip. The task ahead was to remove the skull from the ground without breaking it and to prepare it for safe shipment to the University of Chicago. First we carefully brushed away the clay to expose the outline of the bones, and then we dug a trench around it. As the trench deepened the clay fell away from the sides until the skull rested on a pedestal extending up from the bottom of the hole. The skull had been in the same position in the ground for several million years, all the organic matter which gives some degree of elasticity to fresh bone had rotted away ages ago, and the mineral material, somewhat replaced, was all that remained. Extending in all directions were innumerable cracks along which the skull would fracture, breaking into a hundred pieces, unless carefully prepared. In order to strengthen the bone material and to partly cement the cracks together, Miller applied several coats of very thin shellac which dried at once. Then overlapping strips of burlap which had been dipped in sour flour paste were plastered over the top and sides of the skull. We visited other prospects nearby, and on returning to our *Titanothere* we found that the few hours' exposure to the intense Badlands sunshine had dried the pasted strips into a rigid shell. Our excavating had left the bone resting upon a pillar within a hole some three feet across. It was a matter of a few minutes, then, to cut through the supporting clay and to lift the skull to the ground, bottom or unpasted side up. A few coats of shellac, and more paste-saturated burlap completely encased our find, and after drying, it was ready to be transported to camp.

The size of the bone of the massive *Titanothere* made transportation a problem worthy of much cogitation. Our Ford truck could traverse roads which were legends rather than actualities, but it was incapable of scaling forty degree slopes, or straddling knife-like ridges. But as the pyramids were made by man power, so was our skull transported to the figurative road where we had left our truck.

Several days of shellacing and pasting followed, and then we again roamed the gully slopes in search of fresh finds. Often we separated in the morning, each hunting the hillsides for his ancient game, and at night, after clearing up our supper dishes we exchanged our day's adventure. Most evenings we returned

ANOTHER TITANOTHERIUM SKULL

with pockets loaded with teeth, portions of jaws of the little water deer and odd vertebrae. And as we swapped stories we spread out the day's finds in corroboration. One evening Miller came in later than usual. I had returned to camp an hour before sundown with a young cottontail which was soon sizzling merrily in the frying pan. Now Miller is one of the most appreciative men that I know in the matters of culinary import, so when he passed my frying pan without comment, and began to empty his pockets I suspected that something of unusual interest had found its way into his day's acquisitions. At last, from the bottom of his bag he pulled out an egg. It was not a contemporary egg, or even one of those old ones of unpleasant repute, but it harkened back to the days when our Badlands were grassy plains with pleasant streams and shady lakes. What manner of bird had laid it will in all probability remain shrouded in uncertainty, but the egg, the size and shape of its barnyard successor, had withstood the load of sediments piled upon it, and, following petrifaction, had come to light some three million years after its deposition in the nest.

Upon one of our rambles, when we had strayed far from the home ranch, we climbed out of a gully which headed by the stoop of a little cabin. It was a shrinking sort of home, unthatched and weatherbeaten, the home of two bachelors and their maiden sister, all well past middle age, who found life's necessities in an unceasing struggle to make their little ranch support a diminishing herd. It was a disheartening struggle, for year by year the Badlands had drawn closer

about their acres and cut deeper and deeper into their insufficient pasture land. So much we heard later.

As we emerged from the gulley, at its very head, within a few yards of the doorway, Miller dropped to his knees and began to dig in the manner that I had come to recognize as indicative of an unusual find. A few well-placed prods with his awl confirmed his surmise—here, just showing through the clay, was a cat skull, arches intact, the jaw in place—a gem which would well reward a field season's searching.

We had barely begun our preparations for collecting our find when the elder rancher joined us. He was courteously firm in his refusal to permit us to collect the skull; to do so, he explained, would be in defiance of scriptural teaching. These bones were man's proof of the Mosaic flood, evidence that could not be disputed, and their removal could only be interpreted as an unethical and unchristian attempt to destroy the evidence of the flood in order that such heretics as we would no longer be confronted by material proof of the literal exactness of the Old Testament. So much he gave in explanation of our ejection from his property. We retreated with as much dignity as the situation permitted, scoffing a bit at the old man's argument, but impressed by and respecting the sincerity and conviction of his beliefs.

I tell what followed with a least bit of shame, not at our success in securing the skull, but at the way in which we secured it.

We spent the next two days watching the cabin from a neighboring hill, and at last saw the three old people climb into

MILLER COLLECTING A FOSSIL TURTLE

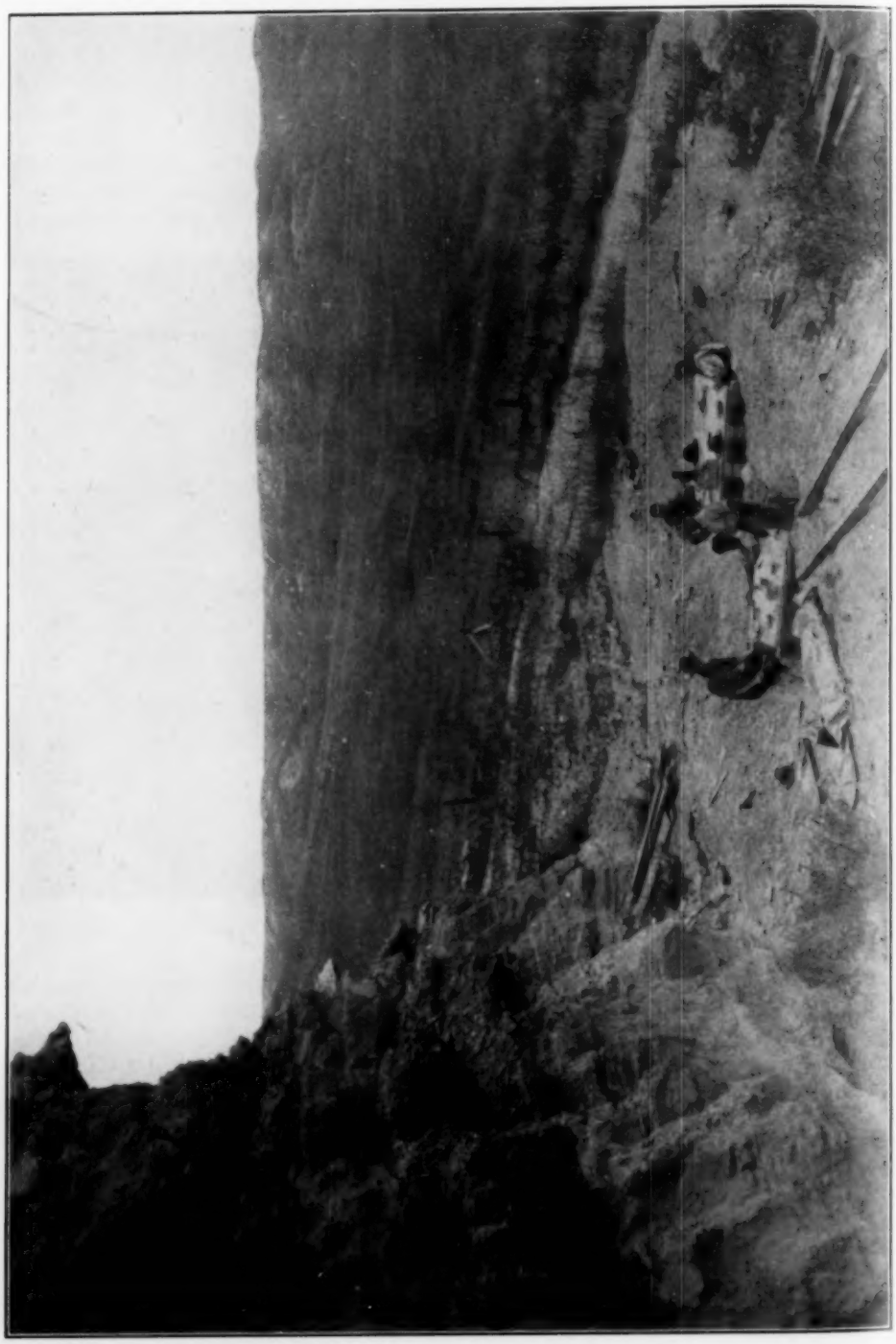
COLLECTING A RODENT SKELETON

the buckboard and disappear into the canyon on the road to town. Two hours later the cat skull was in Miller's bag and we were exercising our paleontological technique in planting the skull of an *Oreodon*, a dozen of which could be found in an ordinary morning's collecting, in the exact position, a hundred feet from the cabin door, from which we had plundered the first skull. That the cat should have been collected for the university does not seem to me to be worth debating; that we resorted to stealth to take it seems justifiable under the circumstances; but that we should have deliberately planted an *Oreodon* in its place is an act for which I have many times since felt just a bit ashamed of myself. But, after all, the old people will never know the villanies to which fossil hunters will descend.

AT NIGHT WE SMOKED AND SWAPPED STORIES

One of our best skulls was acquired through barter, a carton of cigarettes for a perfect skull of one of the giant pigs. Some one at Harrison told me of a skull about two feet long that had been found by a ranch hand in Hat Creek Basin. Without consulting Miller, I rode out to see what manner of beast the cow-hand had found. The ranch seemed to be deserted as I rode up—a few horses moved restlessly in the corral, but there was no sign of human activity. At one side of the porch, propped against the house wall, was the skull that had brought me from Harrison. It was not as large as rumor had made it, but its perfection was beyond anything that we had so far come across. Long snout with tusks, cranium complete, both arches present—it was a thing of beauty. Now I consider myself possessed with normal respect for the eighth commandment. Under ordinary circumstances I would re-

COLLECTING A RODENT SKELETON



EXCAVATING IN THE AGATE SPRINGS FOSSIL QUARRY

EXCAVATING IN THE AGATE SPRINGS FOSSIL QUARRY

gard theft with reprehension. At that moment, however, I had considered the probability that the rancher might not see fit to allow me to take the skull away, and I was walking out of the gate with the prize under my arm. Then I met the rancher. My explanation—I've forgotten what it was—was probably a bit weak, but in a country where doors are never locked, honesty is assumed in all men. I admired the skull. I praised it. I might even have rhapsodized over it, but my best enthusiasm failed to suggest to him that his gracious gesture would have been to have presented me with it. Finally I asked him for it. He was unresponsive. It seemed that he valued that particular skull as the biggest that he had ever found. Folks came to see it, and in sparsely peopled countries that which draws visitors is prized by all men. Flatly, he refused to part with it.

To hide my disappointment in a graceful manner, I lit a cigarette, and being resentful I did not offer one to him. As we talked crops and weather by way of parting I began to recognize delicate suggestions that a cigarette would be appreciated. Being still resentful I ignored the hint. At last he confessed being out of tobacco, and being unable to drive to town that day. That was my chance.

I said, "There is a carton of cigarettes in my bag. You have a skull. Let's swap." We swapped, and the skull, duly mounted, reposes in a case in Walker Museum.

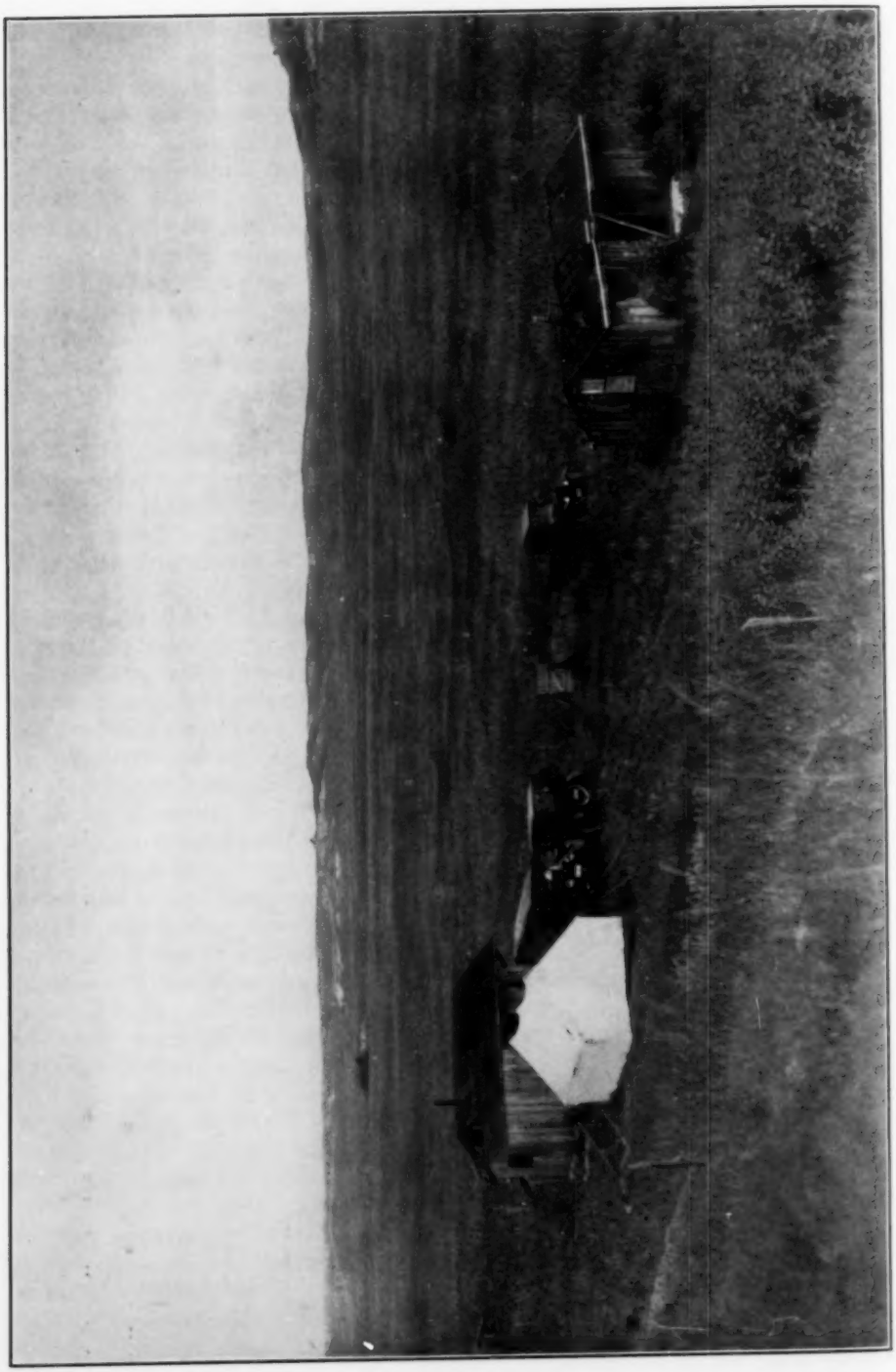
At the end of five weeks the time when the funds which the university had appropriated for our expedition would be exhausted was uncomfortably near. We had accumulated a half ton of fossil bones, representing a score of animal species, all carefully boxed for the journey to Chicago. Our finds had been assembled in our camp at the foot of Pine Ridge, eighteen miles away and several hundred feet below the railway at Harrison upon the upland to the south. The road to town threaded its precarious course up a miniature canyon, continually recrossing the stream bed. We had found on our trip to town for provisions that the rapidly ascending road could not be taken in "high." We had also found that three canteens of water administered periodically to the radiator of our truck would prevent our being mistaken for a traveling geyser.

There followed two days of hard labor. Our truck, loaded to capacity with boxes and crates of bones, crawled up the canyon trail to the freight depot, discharged its cargo and returned for more.

It was with a feeling of relief from oppressive responsibility that we watched our precious bones being loaded into the freight car. The boxes might be torn board from board on the trip home, but it would be the will of Allah and beyond our help.

There remained a visit to the ranch of Captain James Cook and his Agate Springs fossil quarry. Perhaps pilgrimage would better express the spirit in which we drove south from Harrison, for Captain Cook was the beloved friend of fossil hunters throughout the country.

Miller told me about the Agate Springs quarry as we drove along—how the captain's son, Harold J. Cook, had homesteaded the fossil hill in order that the museums and universities of the world might be free to collect its treasures and that no single institution could control their distribution. How Captain Cook, after an adventurous youth in which ranching and Indian fighting alternated, settled at the headwaters of the Niobrara River, in Sioux County, Nebraska, and became the respected friend and trusted adviser of Red Cloud and his chiefs. How his counsel preserved peace between the Sioux and the early settlers, and how in his maturity his unfailing interest in the world about him had led to the discovery of the Agate Springs fossil quarry. Miller



HAROLD COOK'S HOMESTEAD CABIN,
NOW THE CAMP OF THE AMERICAN MUSEUM OF NATURAL HISTORY.

told of Captain Cook's friendship with Professor O. C. Marsh, of Yale, one of America's great students of ancient mammalian life, and later with Barbour, Osborn and Matthew. It was a story of the keenest fascination, and I again experienced the joy of the adventure as I read Captain Cook's autobiography.[1]

With the exception of the scrub conifers upon Pine Ridge we had not seen a tree for over a month. I was not prepared for the park spread out below us as we stopped at the edges of the valley which the Niobrara River had cut in the undulating uplands. For miles we had been driving through a sage-green landscape in which dryness was the dominant note, and then, at the descent to the river, we saw trees, scores of them, and in the center of the grove the homiest of ranch houses. Years ago Captain Cook had planted the grove, and with unceasing love he had watered it; indeed a miniature irrigation system brought moisture to the roots of every tree, and now, in justification of the care lavished upon it, here was a paradise in the desert.

We crossed the bridge and drew up before the ranch house. It was not Miller's first visit, for in years past collecting had brought him to Agate Springs. Captain Cook greeted us with the hospitality traditional of the west, but which is retreating even there before industry's smug self-sufficiency. We were shown over the grounds and came to rest in Harold Cook's museum and workshop. He, the captain's son, was a boy when the early fossil discoveries were made. His imagination, fired by the relics of ancient life which the rocks yielded, spurred him to seek knowledge of that early life and when, in later years, after his studies at the University of Nebraska and at Columbia, he returned to the business of ranching his researches in the local paleontology yielded a museum of more than passing interest.

Toward evening we pushed on to the quarry, paralleling the Niobrara for two or three miles. Other fossil hunters were in camp. Dr. Matthew and Mr. Thomson, of the American Museum of Natural History, occupied the old homestead cabin and camped nearby were parties from the universities of Michigan and Kansas. Community of interests is the best formula for fellowship, for in our brother collectors we found countless stories of fossil hunting in the early days of the Cope-Marsh rivalry, when Indians still considered the skin of a "bug-hunter" just as white as that of a pioneer.

Our moments of keenest enjoyment come unbidden and unplanned. Such times of unalloyed contentment, when we forget the humdrum monotony of everyday life and are keyed to the reception of all that is exotic and unreal, when the glamor of adventure cloaks the unadventurous and we ride roughshod over our inhibitions of rationality are never consciously induced, but are always byproducts of one's surroundings, coming at the unexpected moment and vanishing at the recognition of the mood. Later, I realized that as we sat about the fire listening to yarns of fossil collecting at the far corners of the earth I had slipped into that realm of enviable irrationality, where the stories of mild adventure donned a glamor which can never be set down. It was early morning before the last reminiscences were over, and I had drifted back into the everyday. Indeed I must have retained a residual vision of that fantastic kingdom into which I had strayed, for dreams of curious creatures of extramundane aspect appeared during the remaining hours of darkness.

Morning brought back the familiar world. Three conical hills stood out

[1] "Fifty Years on the Old Frontier," by James H. Cook: Yale University Press, 1923.

HAROLD COOK'S HOMESTEAD CABIN, NOW THE CAMP OF THE AMERICAN MUSEUM OF NATURAL HISTORY.

upon the valley flat. That nearest us, University Hill, contained the long heralded Agate Springs fossil quarry. After breakfast we ascended the slope to the quarry where the parties from the universities of Michigan and Kansas were already at work, removing great blocks from the floor, for here the fossil remains were in such numbers that their removal from the rock could best be done in the home laboratory. How such a jumbling of skeletons of the rhinoceros, *Diceratherium,* could have occurred is one of nature's jealously guarded secrets. If one imagines a swirling river rushing across a grass-covered plain, and then, in his mind's eye, watches a great rhinoceros herd struggling to ford its treacherous bed, sees them falling one by one in the struggle to breast the current, and swept away into an eddy down the stream, there to swirl around and around until the meat has rotted from the bones, and skeleton after skeleton has dropped to the river's bed, he has as adequate a conception of the secret of the great bone accumulation as have the paleontologists who unearthed the storehouse.

I remembered a slab from the quarry floor which Miller had collected in a previous year. He had removed a block some three by five feet in size by cutting a channel around it and then undercutting the boarded up slab. In his laboratory he had chiseled away the sandstone, leaving the bones which he exposed standing in relief against the matrix. They were jumbled as though a dozen disarticulate skeletons had been heaped together—skulls, vertebrae and digits, and then the whole mass imbedded in sandstone plaster.

Two such slabs were in the process of being removed as we reached the quarry. I wanted a picture of the collectors at work, and so I climbed to a nearby hillock and set up my tripod. Just as I had thrown the focusing cloth over my head I heard a sound which had become familiar in my weeks in the Badlands. It was akin to the noise which some katydids make by scraping their spike-studded jumping legs against the wing coverts, and yet it was not a katydid. Soon a similar sound reinforced the first. By that time I was several jumps away from the spot and calling over to the quarry for a pick. When the stone on which my tripod rested was turned over, two very angry rattlesnakes hurled defiance to an unfriendly audience. As the American Museum party was collecting for shipment to the Bronx menagerie such rattlesnakes as were incidental to the business of bone-hunting, we succeeded in roping the rattlers with a noose, and with Miller at one end of the rope, I very uncomfortably at the other, and the two snakes dangling in the middle, our procession descended upon the cabin where the new captives joined some half dozen of their fellows in a sugar barrel.

The day following found our truck stored at Harrison for the next field season, and Miller and me uncomfortable in the habiliments prescribed for traveling. We were going to different parts of the country, and as Miller's train began to move he called back to me, "Bill, you almost made a paleontologist."

RADIO TALKS ON SCIENCE[1]

WINTER'S MUSIC

By Dr. W. J. HUMPHREYS

THE U. S. WEATHER BUREAU, WASHINGTON, D. C.

The Song of the Four-Horse Wagon

Did you ever hear the happy, cheery song of the four-horse wagon? If you ever did, you have not forgotten it, and you never will. When the air is still and very cold, the creak and cry of the crumbling snow and the high-pitched notes of the passing wheels make sweet music that in later life arouses the fondest memories of home and childhood days.

As children we were not always content just to listen and wonder, however sweet the sounds, but sometimes asked our elders: "What makes the wagon sing?" If they told us the snow did it, we, child-like and scientist-like, asked how. Then the subject was changed, and few of us to this day know how the snow makes the wagon sing.

It doesn't always sing. When the temperature is only a little below freezing the snow merely packs to streaks of ice and the rolling wheels are dumb. They find their voices, high-pitched and clear as a bell, only when it is so cold that the snow will not cohere, and their course therefore is no longer marked by ribbons of ice, but by paths of crumbled and powdered crystals. This, then, is the key to the explanation we want. When the conditions are just right for the fine old sport of snowballing the crystals partially melt under the pressure of the wheels and flow together without slip or jar, just as they mould to balls under the squeeze of the hands, only to refreeze, now in a united mass, as the wagon passes on and its weight is removed. When, however, the snow is very cold, it does not melt but snaps and breaks like glass beneath the steel tires of the passing wheels. Every break, every sudden slip and readjustment of the crunching snow not only jars the air directly, as it does under our boots, but also indirectly through the simultaneous and consequent tremors of the wheels and other parts of the wagon. But here our knowledge, at any rate my knowledge, of this fine example of winter's music abruptly ends. Does the snow play only the part of the rosin in the case of the fiddle and the bow, imparting different notes to different wheels, but always the same note to any given wheel whatever its speed or load? Or, on the other hand, do big wheels and little wheels, heavy wheels and light wheels, all sing the same note, a note dependent on some inherent property of the snow and nothing else? What an opportunity is here for a whole series of most interesting investigations!

The Hum of the Telegraph Wire

Another question many a bright child asks without, as a rule, getting a satisfactory answer is: "What makes the wires hum?" If you tell him, and truthfully, that it is the wind, he comes back at once with his favorite poser, "Why?" And in this case a poser it surely is, if we may judge from the variety of silly answers that seriously have been given to it. However, experiment has gone a long way, though not yet all the way, towards furnishing the correct answer.

[1] Broadcast from Station WCAP, Washington, D. C., under the auspices of the National Research Council and Science Service and the direction of Mr. W. E. Tisdale.

If we fasten a light strip of cloth to the side of a slender pole when a stiff breeze is blowing, we will see that it does not stand out straight and quiet, but waves and flutters. And the same thing occurs, as long as we can follow up the experiment, with change of diameter of rod and size of flag. Finally, smoke particles show that even the passing stream of air itself flutters in the same general manner, with a frequency that increases with the strength of the wind and with decrease in diameter of the obstructing rod. There is, then, a fluttering eddy of air attached to every wire exposed to the wind—a fluttering generally fast enough in even very moderate winds, to make a musical note. This fluttering, in turn, produces slight variations of the same period in the pull on the wire, hence in the tug on the supporting poles, which therefore become sounding boards, increasing the volume but not the pitch of the hum. Of course telegraph wires, and others too, sing in all seasons, but as they sing loudest when the wind is brisk and transmit stronger tugs on the poles when tightly stretched, as they are when contracted by cold, their song too is, in the main, a joy of frosty weather.

It would be pertinent to ask here why the stream of air around a wire in a wind flutters so regularly as to create a musical sound, or, indeed, flutters at all, but the answer to that question even in its present imperfect stage, can only be given in pages of mathematical equations —the most concise, as written, and elegant of all languages, but wholly unspeakable.

The Dirge of the Lone Pine Tree

When the mood is right, and no one near to distract, there is a peculiar pleasure in listening, on a windy winter night, to the dirge of a lone pine tree, as it ceaselessly wails in deepest sympathy for whatever loss your own memory may recall or fancy suggest. But when the spell is broken you may ask yourself, "How does the old pine tree get its sighing and wailing voice?" The answer now is easy. Every one of its myriad needles produces a little vibrating eddy in the wind that blows across it, just as the telegraph wire does, and this vibration is fast enough to make a musical tone. The voice of a single needle usually is faint beyond the perception of the most delicate ear, but just as a swarm of bees produces a great buzzing noise where the individual bee could not be heard, so too the voices of a million pine needles blend into a loudly wailing dirge.

Other trees have voices too, mere rustles in the summer when their leaves are on, but coarse and indistinct mumbles in the winter time, caused by the eddying winds about their twigs—a coarser and less distinct voice than that of the pine, because the twigs are larger than the needles and more irregular in size. Nevertheless, the winter murmur of a forest of trees of any kind, as the wind rushes through them, is a pleasant sound to hear, unless indeed we fear too much the coming storm such murmur often foretells.

The Howling of the Wind

One of the greatest pleasures of a wild winter's night is listening to the howling of the wind as it sweeps past the chimneys and over the gables. Most of us are content just to let it howl—to "take the good the gods provide," and ask no questions, but a few are curious to know how the blustering wind gets all its voices, or, indeed, any voice, but our curiosity has never been fully satisfied. We have only learned that here, too, the sounds are caused by an endless succession of eddies produced in the wind by the obstacles over which it is blowing; but the whole story we do not yet know.

Booming of Lakes

In any cold lake region a familiar winter sound is the occasional boom heard far and near as, under the strain induced by a great difference in temperature between its upper and under surfaces, and in other ways, a thick sheet of ice snaps and tears in long cracks and rifts.

The Bursting of Trees

During an intensely cold wave one may hear in a forest an occasional "pistol shot" where there is no pistol, and none to shoot it. It is only the outer shell of a tree splitting under the great strain caused by its cooling faster and therefore shrinking faster than the inner wood. This is not a frequent note in the winter's music, but it may be very impressive, or, indeed, startling, if one happens to hear it while alone in a forest on a dark night.

The Cracking of Joists and Rafters

A good thing to keep one awake in the wee hours of a bitterly cold night is the snap, snap, bang, of the joists, rafters and other portions of an exposed country house, as the tug of the cold jerks their joints into new adjustments. We listen for the next bang, wondering when it will come, then the next, and the next —sometimes enjoying it, but more often, perhaps, wishing we could go to sleep.

The Rattle of the Sleet

When the temperature is only a few degrees below freezing, and a storm is gathering, there occasionally comes a faint tick on the window, as of a grain of rice thrown against it, followed soon by another, and that by still others, faster and faster, until there is a continuous rattle, varying in volume with every gust and eddy of the wind. This is the rattle of the sleet, a sound peculiar, of course, to the winter, and disagreeable or pleasant owing, partly, to whether we have to go out in the storm, or may stay indoors, snug and dry, where the artificial weather is gentle and balmy.

The pth, pth, of the Glowing Fire

When a big wood fire, one of the finest pleasures of a winter in the country, is well burned down and there is a great bed of glowing coals in the ashes, we often hear a muffled popping, pth, pth, somewhere in the fire, but exactly where we can not be sure. On such occasions our grand-dads used to say: "It is going to snow," and very often they were right, because on so raw a day as that which usually just precedes a snow one is apt to have a good big fire. Some said: "The fire is spitting snow." Others, more elegantly, but less accurately descriptive, said: "The fire is treading snow."

These faint but fascinating sounds are, apparently, owing to little explosions of combustible gases coming up from hot bits of wood, charcoal and glowing embers more or less buried in the ashes.

There are, of course, various other interesting bits of winter's music, but we well may end with the pth, pth, of the fire, since it so often is heard as the evening is wearing on and the last fire of the day is dying down. Indeed in a very real sense it is winter's lullaby, or goodnight song, for under its spell we do grow drowsy and nod.

OTHER UNIVERSES

By JAMES STOKLEY

SCIENCE SERVICE, WASHINGTON, D. C.

WE do not know when man first began to study the stars, but among the records of many early peoples we find that astronomy had already become a well-developed science. To the ancient Greek philosophers the relation of the earth and the celestial bodies that they saw in the heavens was a major problem. One hypothesis, attributed to Eudoxus, who lived in the fourth century, B.C., held sway for over fifteen hundred years. Known as the Ptolemaic theory, after Ptolemy, the Egyptian astronomer who wrote of it in his great work, the "Almagest," this stated that the earth was at the center of the universe and that the planets and fixed stars revolved around it.

But, long as it held, man and the earth were finally deposed from this important position and the Ptolemaic theory was superseded by that of Copernicus, which placed the sun at the center and made the earth but one of a family of planets that revolve around it. However, so far as Copernicus was concerned, the sun was actually the center of the universe and the stars were fixed on an infinitely distant sphere. With the invention of the telescope, in 1610, and its use in observing the stars, first by Galileo, and then by many others, it became apparent that the sun was a star, and, conversely, that the stars we see in the night sky were suns, but so far away that they appear as mere points of light. It is difficult to comprehend the distances of these orbs, so suppose I were to make a model to scale. In my hand I have a ball an inch in diameter representing the sun; a dot a hundredth of an inch in diameter and nine feet away represents the earth, but Alpha Centauri, the nearest star, is in Columbus, Ohio, 330 miles from Washington! Actually the sun is 865,000 miles in diameter, and the stars are so far away that astronomers can not use miles to express their distances. Instead, they employ the "light year," equal to about six trillion miles, or the distance that a beam of light, travelling 186,000 miles in a second, as fast as the radio waves that carry my voice to you, would go in a year. Alpha Centauri is a little over four light years away, Sirius, the Dog Star, about seven and a half, while the distances of most of the stars are measured in hundreds, or even thousands, of light years.

Distant as the sun's neighbors are, with it they form a system, or universe, of stars, which, as the English astronomer, Sir William Herschel, showed about a century ago, is approximately the shape of a watch or a grindstone. The sun is not far from the center and as we look towards the edge of the grindstone we see such a vast swarm of stars so closely packed together that to the unaided eye they appear as a continuous area of light, which we call the "Milky Way," but in other directions the stars are not so numerous. Even a small telescope reveals the individual stars in the Milky Way, while with a larger glass we see that some are double, that is, instead of consisting of a single body, there are two, which revolve around each other. Still others, which to the naked eye, or with a small telescope, may appear single, are really multiple, consisting of three or more separate bodies.

In addition to these, with a moderate-sized telescope, we may see some star clusters, groups of thousands of stars, some irregular and some of a globular shape. In a small telescope, or under

poor conditions with a large one, these clusters look like continuous areas of light, similar to the Milky Way when seen with the unaided eye. Herschel, who had the largest telescope built in his day, saw the constituent stars for the first time in some of these clusters, so when he saw other nebulous objects that could not be separated with even his highest powers, he concluded that they too were made of swarms of stars that might be seen with a still more powerful instrument. Some, he suggested, might be actual "island universes," similar to our grindstone-shaped cluster and far beyond its limits.

But about 1860, astronomers began to make use of a powerful new tool, the spectroscope, by which it was possible to separate the star light into a rainbow-like spectrum, crossed by numerous dark lines, which, to those who can read them, reveal the composition of the star. Principally in the hands of another English astronomer, Sir William Huggins, the spectroscope was applied to the study of the nebulae, and most of them proved to consist of glowing gases. Such nebulae, then, were actually the irregular clouds of light that they appeared to be, but there are others that display a definite spiral structure, something like a Fourth of July pinwheel in appearance. Only one of these is bright enough to be seen by the unaided eye as even a faint spot of light under the best conditions, but it has been estimated that at least 700,000 are within the grasp of modern telescopes. When looked at, even through the great 100-inch reflecting telescope at the Mt. Wilson Observatory, they are disappointing, but when photographed with an exposure of many hours, their light can "soak in" on the sensitive plate and their real form may be appreciated.

Some of the spirals are seen "head on," others at an angle, and still others display to us only their edges, for they too have the shape of a grindstone. All do not show the spiral structure equally well, but they can be arranged in an almost continuous series, depending on the perfection of their shape, which suggests that each might represent a different stage of development. But perhaps their most significant characteristic is that while the stars, clusters, gaseous nebulae and all the other celestial objects are vastly more numerous in the Milky Way than elsewhere in the sky, not a single spiral has ever been found in this luminous belt!

The spectroscope also tells something about them. Instead of showing a spectrum of bright bands of color like that of the gaseous nebulae, they give one resembling that of the stars, but not of any particular star. Rather is it like a composite spectrum that might be obtained from a large mass of stars closely packed together. This fact, combined with those of their shape and distribution, seemed to furnish a clue to their nature. Might they not be actual island universes, like our own, and outside its limits? This seemed reasonable, and was advocated by several eminent astronomers, but what was apparently important evidence against it was furnished by Dr. Adrian Van Maanen, of the Mt. Wilson Observatory.

The spiral arms of some of these nebulae are not entirely continuous, but show knots, or condensations, and by comparing photographs made twenty years previously by the 60-inch reflecting telescope of the observatory with others that he made of the same objects a few years ago, he found that apparently the material of which the nebulae consist was moving outwards along the arms, at a speed to take it completely around in a quarter of a million years. While such a speed might seem slow, it would actually be exceedingly fast, for if the nebula was one hundred light years across, which would be far smaller than our universe, and scarcely more than the distance of some of the

nearest stars from the sun, the material going around it in a quarter of a million years would have to travel nearly a million miles an hour! If the nebulae were far enough away, and sufficiently large, to be actual island universes, the speed would have to be impossibly great for any material substance, so this seemed to be the death blow of the island universe theory.

But sometimes scientific theories have a habit of coming to life after they have been killed and buried. During the past year Dr. Edwin P. Hubble, of the Mt. Wilson Observatory, announced that he had discovered in several of the spirals a number of Cepheid variable stars. These periodically become bright and then faint again, but unlike other kinds of variable stars, the greater their average brightness, the more rapidly do they vary. Their apparent brightness at any time may be measured by the astronomer from the strength of their images on his photographs, the period of their variations may be found by comparing plates made at different times, and this gives their actual brightness. We know how rapidly light diminishes as it passes through space and so the ratio of the actual and apparent brightnesses enables us to calculate their distances. Suppose you see a light so many feet from you. If you know how far it is you can estimate its actual brilliancy, but also, if you have in some other way found out how bright it really is, then you can estimate its distance.

Using this method Dr. Hubble found that some of the brightest, and presumably the nearest, of the spirals are at a distance of about a million light years! This places them definitely outside our system, which, though estimates of its size vary, is hardly more than three hundred thousand light years across. But to clinch his argument, Dr. Hubble photographed two of the spirals with the highest powers of the 100-inch telescope at Mt. Wilson, and actually showed parts of them as hordes of faint stars, proving them to be actual island universes, just as Herschel suggested so many years ago! Recently I had the pleasure of visiting Dr. Hubble at Pasadena, and he showed me his original plates, some of which he made last summer, and he told me how, by means entirely independent of the Cepheid variables, he had remeasured the distances and found them entirely in agreement with his previous work. Columbus discovered half a known world, but how much greater is this man, who has discovered a host of new universes?

But, you ask, what happens to Van Maanen's work, and how can it be reconciled with the new discoveries? These questions are being asked by many astronomers, particularly Drs. Van Maanen and Hubble themselves. As Dr. Van Maanen is recognized as a skilful observer, no one questions the accuracy of his results, but the effect may not be a real one. For instance, in some of the spirals spectroscopic evidence indicates that the arms are closing inwards, instead of opening outwards. In 1918, a new star flashed out in the constellation of the Eagle, and a series of photographs of it showed what was apparently matter moving out from it with a speed comparable with that of light itself. This was shown to be, not the actual motion of matter, but the front of the wave of light from the star as it burst out from its previous obscurity. It had been surrounded by clouds of cosmic "dust," dark matter previously invisible, but as parts of this dust cloud farther and farther from the star became illuminated, we saw what was apparently a rapidly expanding cloud. Perhaps something similar is occurring in the nebulae.

In any event, we can not but feel all the more the minuteness of man in the great Cosmos. From an earth at the

center of everything according to his former ideas, his home became but one of a number of planets revolving around the sun, his sun became but one of many stars, and now his system of stars turns out to be but one of countless hordes of universes! Is this the last step? Who can tell?

WHY THE SEA IS SALT

By G. W. LITTLEHALES

HYDROGRAPHIC OFFICE, WASHINGTON, D. C.

THE approach to the discussion of the subject, "Why the Sea is Salt," is to be sought in considerations respecting the origin of the earth. The penetration of mathematical astronomy and geophysics into the origin of the earth has resulted in ranging the oceanographer in the ranks of those who have maintained that surface geology, like volcanic, does not demand the excessive temperatures which would have necessarily attended the formation of this planet by the gaseous-molten process of the nebular hypothesis. The oceanographer's position in this respect is prompted by the necessity which confronts him of accounting for an ocean of the volume of that which actually exists on the earth.

Spread over more than two thirds of the surface and yet amounting to but little more than one one thousandth part of the whole volume of the globe, the ocean, with its average depth of two miles, is represented by a sheet of water of a thickness of only one four thousandth part of the diameter of the earth. It is not without importance to point to the analogy that this depth is no greater than the thickness of the film of water that would cling by capillary attraction to a rubber ball of four inches in diameter, being on that scale only one one thousandth part of an inch. From a sphere of this size composed of suitable material such a film could easily be exuded.

By the nebular or gaseous-molten hypothesis, the original earth-nebula contained the materials of the present ocean and atmosphere. When the solid earth-body had cooled sufficiently, condensation of the water of the primitive atmosphere would have taken place to form the ocean. But the indications are that by this process far more water would result than the world contains.

Probably, then, the ocean has not had its origin in the primitive atmosphere surrounding a hot earth-body slowly solidifying from a gaseous-molten phase.

As knowledge increases, old beliefs not only may lose their value, but may thwart progress. The spirit of critical inquiry is necessary.

> New occasions teach new duties;
> Time makes ancient good uncouth;
> They must upward still, and onward,
> Who would keep abreast of Truth.

It is by regarding the earth as having been evolved by planitesimal accretion around a nucleus condensed from a part of the material of an eruptive bolt from the sun that a more rational explanation of the origin of the ocean is reached. It is far more likely that it has come from the water chemically combined with and absorbed by the planitesimal dust. As this solidified and then became disintegrated, the water was liberated.

At first, when the earth was small, the water would escape as vapor into interstellar space on account of the deficiency in the intensity of the embryo earth's gravitational field to retain water vapor as an atmosphere. It is doubtful whether Mars, with a mass one tenth as great as that of the earth, can now do

so. But, grown to its present mass, it is even possible that the earth continually captures water molecules from outer space, and it is also probable that the water included in the last planitesimal accretions is still being exuded. On this view, then, the ocean is very slowly increasing in volume.

When first the ocean was chained captive at the wheels of the evolution of the earth in the basin that became the crucible in which was distilled the first living cell, its waters already contained saline constituents dissolved out from the planitesimal materials that cohered to form the nuclear-earth, and age-long accessions to the salts of the sea have been brought down to it by the rivers. But either the materials thus reaching the sea were different in the past from what they are now or else there have been processes at work that have made the composition of ocean salts different from river salts. At present the two dissolved mixtures are not the same. In the ocean, the relative abundance of chlorine, sulphur ($asSo_4$), and carbon ($asCO_3$) is in the order named and likewise is the relative abundance of sodium, magnesium and calcium, while a reverse order of abundance of both of these trios of constituents exists in regard to the salts of river-water.

By considering the transformations that take place to make insoluble compounds that constitute oceanic deposits or to generate gases to be liberated into the atmosphere, the changes that must ensue to alter the ratios of abundance of the various substances that are added to the salts of the sea by river-waters are capable of explanation, save only in regard to sodium, which, in some way not yet known, seems also to be undergoing extraction from solution.

When young Nature began to write the history of the earth upon the geological column, it was recorded that the sea was made salt in the beginning as a part of the design of the sublime system of terrestrial adaptations. There is direct evidence that the ocean in the early part of Paleozoic time was highly saline, for there were deposited from the waters of the Silurian Sea saliferous strata which constitute the Onondaga salt group and the Trenton and Chazy limestone series, in which the relics of marine organisms largely abound, to prove that they result from the sediment deposited by the ocean in that age. The salts of the sea have fed, throughout the ages, countless living things which have thronged its waters and whose remains now form the rocks of continents or lie spread in beds of unknown thickness over an expanse of the bottom of the ocean exceeding, by eighty million square miles, the total land surface of the earth; they have lent the substance to build the fringing reefs of the land and all the coral islands of the sea, and there are at present, on the basis of an average salinity of three and one half per cent., in the 324,000,000 cubic miles of water which make up the ocean, more than 11,000,000 cubic miles of salt. This is sufficient to cover the areas of all the lands in the world with a uniform layer of salt to the depth of more than a thousand feet.

What force could move such a mass on the dry land? Yet, so marvelously is its enginery balanced, the ocean has received this great burden, without growing any fuller, and has given perpetual motion to it at the summons of the sunbeam, the zephyr, the polyp.

The salinity of the ocean in all parts of the world is as nearly the same in the proportionality of its constituents as is the blood of a human being in different parts of the circulatory system. To evolve on this planet a world, such as this in which we live, the salinity of the ocean is indispensable. The office which the ocean performs in the economy of the universe by virtue of its saltness, it could not perform were its water altogether fresh.

If the sea were not salt, there would be no coral islands and reefs to give variety to its features; marine organism could not operate upon the specific gravity of its waters, nor give diversity to its climates; neither could evaporation add dynamical force to its circulation, and its waters, ceasing to contract with the lowering of their temperature below 39° Fahrenheit, would give but little strength to its currents.

It is through the agency of the salts in the waters of the ocean that the necessary powers are derived to cause it to exercise, through its circulation, a governing influence upon heat transference and climate and upon the development of vegetation and the well-being of the myriad forms of life in the world.

The three great factors in accounting for the system of currents in the ocean, by which it becomes the great heat distributor of the globe, are changes of temperature, the winds and salinity. The last mentioned becomes an important factor through the immediate and essential differences in specific gravity and consequent differences of level that it produces in different parts of the ocean through the action of evaporation and rainfall.

If, through the fall of rain upon a portion of the ocean or through the action of evaporation in the surrounding parts, the waters of that portion become lighter than the rest down to a certain distance below the surface, two different kinds of motion will immediately occur. The lighter water will be lifted by the surrounding heavier waters until there is no difference in pressure between its lower boundary and the surrounding waters at the same depth; but, as its pressure at all levels above this lower boundary will now have become greater than that of the surrounding heavier waters, it will instantly begin to displace and overflow them. This movement of the lighter water will require considerably more time than the movement of the heavier waters by which it was lifted and continues to be lifted, as its level sinks by lateral diffusion, because the sum of the differences of pressure which caused the lifting of the lighter water was, in the first place, greater than the sum of the differences that caused its lateral diffusion. Secondly, the differences of pressure that caused the first movement must extend all the way to the bottom, whereas those which cause the latter extend no deeper than the lighter stratum itself, and, even within the extent of that, have their chief effect confined to the surface strata.

On the other hand, when the equilibrium of a mass of water is disturbed by causes that do not diminish the specific gravity, the disturbance must extend down to the bottom, and the differences of pressure at all levels beneath the surface must be equal. The equilibrium is then restored by a general movement of the whole mass, which movement is sensible in inverse proportion to the mass that is set in motion. This is the essential cause for the difference in strength between the currents observed in salt and fresh waters, for, of all the current-producing causes which act in fresh waters, only the one resulting from variations of temperature can sensibly affect the specific gravity, while the specific gravity of sea water, besides being much more affected by variation of temperature, is still further influenced by the fresh water which rains upon the surface of the ocean. If the whole basin of the ocean were filled with fresh water and exposed to the most extreme meteorological influences, the currents produced would not be nearly equal either in size or strength to those observed in the waters of the ocean.

So the saltness of the sea is involved in all the great subjects into which the ocean currents and ocean circulation enter. Having contributed to the growth of the continents, it has in a like degree peopled them by influencing human mi-

grations through the streams of the ocean upon which the race of man was spread to the distant archipelagos at a time when there were only rudimentary means for struggling against the forces of nature. Besides its influences in geology and anthropology, it is concerned to a marked extent in the climates of the earth and of the sea, and in their botany and zoology.

THE EFFECT OF SCIENCE ON HISTORY

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LAST December there occurred in the city of Washington one of the most remarkable exhibitions of scientific studies which could be found anywhere on the face of the globe. Back in 1902, through the munificence, particularly through the farsightedness of the late Andrew Carnegie, there was created, with an income now upwards of twenty-two millions of dollars, an institution for advanced research in the realm of pure science. Under this organization have been brought together a band of scientists who ask no more than to be provided with ways and means to carry on their abstruse but epoch-making studies. And so these men are now busy in inquiring into the scientific explanation of such things as magnetic activity, the reason why radio waves hit a "ceiling" in the atmosphere and bound back to the earth; the reasons for earthquakes and volcanic action, with the possibility of charting earthquake areas in order to prophesy where the next quake will come; the means by which the plants catch solar energy and store it up in the earth for the use of man as fuel and food, with the possibility ahead of capturing solar energy and transmuting it into great fuel and food supplies for human beings. The exhibits which were brought together from the four corners of the earth by the Carnegie Institution of Washington afford a striking illustration of the ways in which scientific discoveries will modify our life in the future even more than they have in the past.

These scientific discoveries, so graphically exhibited by the Carnegie Institution, raise most interesting questions for the historian as he looks back over their history and tries to look forward to the future of science and of man.

Is it possible to measure history in terms of science? Is it possible to discover a scientific interpretation of history which will be as important an addition to the field of knowledge as has been the theory of evolution? There are some reasons to believe that some future Newton will hit upon this and that he will give an entirely new interpretation and impetus to the study and to the teaching of history. It will give us a new perspective of our place in the ebb and flow of human affairs and in our relation, not only to each other, and as nation to nation, but in the large sense of our relation to this earth and to the great universe of which this earth is a relatively insignificant and by no means a permanent fixture.

It is easiest to explain the possibility of such an interpretation by casting a historical glance backward and noting the rate at which man since the dawn of history has increased his control over the forces of nature, and then, having noticed this, to compare the rate at which he has secured control over his own nature. In such a comparison the effect of science on human history may be realized.

One of the most unusual things for the student of history to realize is that our age of *so-called* "modern" history, the

years since the discovery of America, is but a brief part of the history of mankind, whose life on this globe goes back at least 500,000 years and probably earlier. The present era of modern civilization and modern science is just the frosting on a very deep and very thick cake, none too savory at the bottom. To-day we are at the top, in material things, of the long process of civilization. We are in possession of scientific tools undreamed of by the great thinkers of antiquity and by our own grandfathers and even fathers. This is because science, with ever increasing rapidity, has been giving to man more and more control over the physical forces of nature. In the future even more than in the past, as the Carnegie Institution exhibition forecasts, we are to expect that the contributions of science will give us increased control over these forces, and over new forces which we have not yet discovered, which to-day we can not visualize even with imaginations already attuned to the startling scientific developments of our age.

For the greater part of human history man has lived without the benefit of science. Some old men listening in to-night can remember back into what seems a different world, so far as modern scientific inventions are concerned. Never did they dream in their wildest dreams of youth that, for example, they would be sitting to-night in their own homes listening to a voice from Washington. One does not have to go back many lifetimes to get beyond the touch of modern life altogether, so far as the achievements of the scientific miracles of recent generations are concerned. The farther back one goes the more static and stationary life is. Let us start at the dawn of history and observe the rate of progress of science since then.

Man's first discoveries were few and far between. It was hundreds of thousands of years before our early progenitors discovered how to make and use fire, the first great invention which profoundly changed habits of human life. Doubtless it was thousands of years after the discovery of firemaking that the bow and arrow was invented, again changing stupendously our remote forefathers' way of living. From then to the domestication of animals must have been another long period, but shorter than the distance from the discovery of how to make fire to that of how to make the bow-and-arrow. From domestication of animals to agriculture, to weaving, to other important steps in the control of natural forces were steps far apart, but, it is important to notice here and to remember, ever closer together in time, as civilization advanced. It seems pretty certain that if we knew all the facts we should find that man's control over the forces of nature has proceeded at a constantly accelerating rate—like the steam exhaust of a locomotive getting up speed, at first the puffs are slowly spaced and labored, then they come faster and faster, almost indistinguishable from each other as the engine approaches full speed. So with our civilization as it has been getting up speed. From the dawn of civilization down to the time of the ancient Greeks, that is to say, for perhaps some three thousand years, the number of epoch-making scientific achievements was very small—that is, from the invention of writing to the days of Aristotle. For the next fifteen hundred years following the discoveries of the Greek scientists, science, relatively speaking, rested on its oars. Men and women in the Roman world lived, worked, traveled, wore the same kind of clothes, ate the same kind of food, used much the same kind of tools, raised much the same kind of crops and went their separate ways in much the same way that they had in the time of Pericles. Some improvements and changes, yes, but none such as to transform very much confirmed habits of living and thinking. Then came the Renaissance and a number of epoch-making scientific inventions and discoveries—the compass, the sphericity of the earth, and with these the new world and the new geography—

the discovery of the solar system and with it a new conception of the place of man and his earth in the larger scheme. Only roughly fifteen hundred to two thousand years had now intervened between epoch-making discoveries; whereas previously such things did not occur except three or four thousand years apart, and even before that, in stretches of six or eight thousand years. From 1400, the time of the Renaissance, to 1750, the age of absolute monarchy at its apogee in Europe, the world was profoundly affected by science. It was in the eighteenth century, for example, that the beginnings of modern chemistry and physics, and with them of medicine, were laid. After a period this time of only three or four hundred years, man, thanks to the increasingly influential aid of science, had again perhaps doubled his control over the forces of nature and in a much shorter time than it had taken him to double his scientific capital in previous ages. Think of the advancements which took place in the next seventy-five years, between 1750 and 1825—the invention of power machinery, particularly of steam power, and the industrial revolution which was a consequence. If we look on our stock of scientific inventions as one looks on his capital invested in a bank or elsewhere, we see that once it took man, say, three or four thousand years to double his little stock of scientific capital; later he doubled it in half that time, namely, in about fifteen hundred or two thousand years, and that he continued to double an increasingly large scientific capital in increasingly short periods of time. From 1825 on one can appreciate readily enough the rate at which science has progressed, until now it seems that about every decade or two we double the control which science has gained for us over natural forces. And science is still speeding along. We are only beginning to get up speed. Almost over night the world of material things around us seems transformed.

What I have just said is, of course, to some extent conjectural. But if we knew enough of the facts and of the history of man for, let us say, the last twenty-one or two thousand years, we might be able to plot a curve representing the rise of science from, let us say, 20,000 B.C. to 1925 A.D. For the first ten thousand years that line would run along the bottom of the page with only a small ascent marking the advance of science from the invention of fire-making to that of the bow-and-arrow. After that during the next five thousand years, from bow-and-arrow, say, to domestication of animals, to agriculture, to the invention of writing, the curve would rise as much as it had in the previous ten thousand. From the invention of writing to the time of Greek science the curve would again go up, in now less than twenty-five hundred years, to a degree equalling the whole sum of previous advance. As our civilization has been getting up speed our stock of scientific knowledge has doubled itself at increasingly short intervals. Possibly it has acted somewhat like a dollar out at interest, which might at first at infinitesimal rate of interest double itself in ten thousand years, then the two dollars to double in five thousand years, the resulting four dollars in twenty-five hundred years, the next eight dollars in twelve hundred and fifty years, and so along, until at length rapidly larger sums are doubling themselves at very short intervals. Very roughly speaking, this suggests the way our stock of scientific knowledge has been increasing. If we knew all the facts, I repeat, we might possibly figure out a mathematical measurement of the advance of science, and thus discover a dynamic law of history—once suggested by Henry Adams—which would be as important in thought as the theory of evolution.

It is quite possible that between 1925 and 1940 science will have advanced as much as it has done in hundreds of years in the past. We know we are now going ahead at a stupendous speed. Can we keep this up indefinitely? Are we likely

to get going so fast that we are in danger of running off the track? This is what many thinkers to-day want to know, and they are calling on the historian to tell them.

Remembering this ever-increasing, this dizzy speed of scientific progress in recent times, let us note whether human nature, human physiology, human psychology has been changing. If at all, these factors have changed only very slowly. We are somewhat different now than in the time of Tutankhamen. Thanks to medical science, we live twice as long. Our social organization and our political organization are somewhat better, but our progress in these directions has been painfully slow. While we have been speeding ahead so fast in getting control of physical and chemical nature we have done woefully little in getting control of human nature. Our human nature, that is, our human body, is not very much different now than it was in the time of ancient Egypt. We fight wars, we experience revolutions and we do them in more deadly and more rapid ways. We have the same human hatreds, fears, hopes and loves. What if human nature should get out of control in another great war, in let us say 1940? What if in 1940 mankind should loose, for purposes of destruction, the physical forces which science will have harnessed in the next fifteen years? The answer is suggested to me by some words of Secretary of Commerce Herbert Hoover, which he is quoted as having used in an Armistice Day address at Los Angeles: "The world has learned many lessons from the war, but none more emphatic than that its increasing terribleness will, if repeated again, destroy civilization itself. The mobilization of a whole people into war, the inventions of science turned to destruction and the killing of men will make any other great war the *cemetery of civilization.*"

This is what interests the historian as he turns his attention to the work of modern science as an ever-increasing and powerful factor in human life —the most powerful material factor there is to-day. The historian, noting the increasingly potent factor which science is playing of late years in human affairs, is impelled to ask the questions: Is the control of natural forces we are now achieving in such increasing measure, is this control compatible with our control over human nature? Will our startling and ever more startling scientific inventions get out of hand, through defects of human nature, and end us in a catastrophe that will make us begin all over again? The historian of to-day is becoming more concerned with the relation of science to society in recent times. He will be even more concerned in the near future. If the teaching of history can be presented in such a way as to make the student know where civilization is now and whither it is going, it can in this way emphasize the vital necessity of adjusting human nature to scientific progress, then history may come to have a practical value to be measured in the saving of human lives by the millions and in the saving of civilization itself. The lessons of history will be more availed of, as they were in the Washington Conference for the Limitation of Armaments in 1921, which enabled millions of people to avoid a terrible war. Thus does the study of history become as practical and valuable an everyday sort of thing as chemistry. Indeed it is more so, if one realizes that some great cataclysm in the future if not prevented may knock the props out from under science itself.

The study of history, in terms of human relation to science, is the only way we have to throw a beam ahead on an uncertain road. It is as indispensable to civilization, in these days of rapid scientific inventions, as is a headlight to a powerful motor car speeding ahead on an indifferent country road. It is a conception of history as the headlight of civilization which makes the teaching of it one of the noblest tasks of life.

ASTRONOMY AND AUTHORITY

By Professor JOSEPH MAYER

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ABOUT the time of the death of Copernicus in 1543 and the publication of his now famous astronomical treatise, there were definite signs of a breaking away from the authority of Aristotle in several fields of scientific inquiry, although the most immediate effect was upon astronomy. The movement was slow in gathering strength, for the ecclesiastical power of the period dealt summarily with those who questioned its dogmas, especially if it thought its position to be imperiled. It crushed many brave spirits under its iron heel.

Yet by the end of the sixteenth century the number of "dissenters" had increased considerably. The clerics now became thoroughly alarmed at the growing "heresies" and, hoping to put an end to them, singled out an outspoken believer in the Copernican system, the eminent Giordano Bruno, and ordered him to recant on pain of being put to death at the stake. Bruno refused to recant and thus went to his death; but his dying words live forever in the hearts of men: "I yielded to none . . . in constancy, and I preferred a spirited death to a cowardly life."

Bruno was a contemporary of a number of other fearless thinkers who could not be crushed, among these the fiery Galileo (1564–1642) and the painstaking Kepler (1571–1630), who between them were destined to complete the destruction of the Ptolemaic-Aristotelian cosmogony, which assumed the earth to be fixed, with the sun and the rest of the heavenly bodies circling around it. The burning of Bruno at the stake served mainly, after the first hush of dread had passed, to lash the Ptolemaic-Copernican controversy into a fury, out of which the Copernican system emerged triumphant.

Two outstanding achievements in the field of astronomy served to make this seventeenth century triumph completely possible. One was the perfection of the telescope and its use by Galileo, and the other was the discovery by Kepler of the laws of planetary motion, the keynote of which was the substitution of elliptical for circular orbits to explain the movement of the planets about the sun.

Galileo and Kepler were both eminent mathematicians and astronomers; they held professorships in prominent universities; and they accepted the Copernican theory early in their careers. They were acquainted with each other, at least by correspondence; apparently secured considerable consolation in writing back and forth about their work and their troubles with ecclesiastical despotism; and appreciated the dangers they were running in holding unpopular views. Galileo remarked in 1597 in a letter to his friend that he was withholding some of his arguments, for he did not desire to become, as he put it, "an object of ridicule and scorn . . . so great is the number of fools." Galileo had a bitter tongue and did not mince words on occasion.

At the University of Pisa in his native city, where he received his education and where he later held a professorship, Galileo soon brought unpopularity upon himself because of his original thinking and his keen desire to get at the truth, which desire amounted to a passion with him. His father, an impoverished Italian nobleman, had tried unsuccessfully to make a merchant out of his son and, failing, had sent him to the university to study medicine. But Galileo was interested in pure science, and this interest could not be suppressed. Sitting in the

cathedral at Pisa, during a service, his attention was caught by a swinging chandelier above him. In a spirit of curiosity he timed the oscillations by his pulse beat—for watches had not yet been invented—and noted the curious fact that, although the oscillations were dying down, the time of each swing of the chandelier remained unchanged, a discovery which formed the basis for the subsequent construction of the pendulum clock. Experimenting with pendulums of varying length on his return from the cathedral he discovered a second important fact, *viz.*, that a longer or shorter time of swing is secured by changing the length of the pendulum; and combining the two discoveries, he invented the first instrument for recording the pulse beat of a patient. During this same period of medical study, he accidently overheard lessons in Euclid being given at the home of a friend and induced the tutor to give him lessons also. Soon, the study of medicine forgotten, he was deep in mathematics and physics, mastering the writings of Archimedes and making suggestions along scientific lines which brought him to the attention of the premier mathematician of Italy, who secured for him the chair of mathematics at Pisa.

Here at the very beginning of his career, Galileo performed his famous experiment of dropping a light and a heavy ball of metal from the top of the leaning tower of Pisa to disprove Aristotle's dictum that a heavy body falls faster than a light one. Aristotle's assumption is the common sense assumption, for it is in every one's experience that a piece of paper flutters to the ground more slowly than a stone drops. Yet the difference is due only to the resistance of the air, neglecting which, the paper and the stone would fall with the same speed, as experiments in vacuo amply demonstrate.

In his experiment Galileo used a hundred pound cannon ball and a half pound weight, the compactness of the objects rendering the resistance of the air negligible. He released them together. But as the cannon ball and the weight struck the ground simultaneously before the astonished eyes of the antagonistic crowd that had gathered, only angry mutterings arose. Galileo was called a sorcerer and magician, for not only did the result violate common-sense impressions, but the great Aristotle had taught the very opposite. And what Aristotle taught was not to be questioned, and so, his colleagues reasoned, Galileo must have resorted to witchcraft! The leaning-tower-of-Pisa experiment was but an illustration of how in one way or another Galileo thundered forth his anathemas against the blind antiquity-worship of the day, until his enemies in Pisa forced him to resign his professorship. Luckily, however, his fame had spread and in 1592, still under thirty years of age, he was invited to come to the University of Padua, where he continued his experiments but curbed his utterances somewhat until after his reelection in 1598.

Then came the martyrdom of Bruno, and the spirit of Galileo boiled within him. He watched his opportunity and found it in the appearance of a new and brilliant star in 1604. Here was an object-lesson. How account for a strange star in the never-changing, immutable heavens of the Aristotelians? He unleashed his bitter tongue again. Before large audiences he flayed his enemies and for the first time came out boldly for the Copernican system. Soon he was the storm center of the controversy, with the clerics watching his every move. But Padua was quite tolerant religiously and as long as Galileo stayed there he was safe from actual persecution.

It was at this period that he received word from Holland regarding a crude magnifying contrivance, which his inventive genius seized upon and perfected into the telescope. His first improvement enabled him to see objects nine

times as large and three times as near. He quickly followed this with another instrument which magnified objects nearly a thousand fold and brought them thirty times nearer. This he pointed to the heavens with further devastating results for the Aristotelian cosmogony. Again his trenchant pen and bitter tongue flayed the opposition. "Where is your perfect moon," he shouted, "when through my telescope it shows itself to be all scarred and indented?" "Why assume the earth to be the center of the universe," he continued, "when I see four bodies circling around the planet Jupiter?" His opponents were beside themselves. One prominent critic insisted that since the moons of Jupiter could not be seen with the naked eye, they did not exist. Another simply refused to look through the "devil's glass."

"Oh, my dear Kepler," writes Galileo, "how I wish we could have one hearty laugh together. Here at Padua is the principal professor of philosophy, whom I have repeatedly and urgently requested to look at the moon and planets through my glass, which he pertinaciously refuses to do. Why are you not here? What shouts of laughter we should have at this glorious folly. And to hear the professor of philosophy at Pisa labouring before the grand duke with logical arguments, as if with magical incantations to charm the new planets out of the sky."

With his telescope, Galileo continued to "push back the heavens" and to add to his fame. He discovered a sun spot and by watching its changing positions calculated that the sun revolves on its axis every twenty-four days. He resolved the Milky Way into myriads of tiny stars. He discovered the rings of Saturn. And in scores of other ways he opened up the heavens as they had never appeared before.

By this time Galileo had become the idol of the Venetian republic, under the protection of whose tolerant religious attitude he should probably have remained. But he had long desired to be back in his home in Tuscany, in spite of its bigotry and intolerance and the nearness of Rome, so in 1610 he returned, accepting a position in Florence, where he continued his researches in physics and astronomy and his criticism of the Aristotelians. The ecclesiastics now saw their opportunity and began stirring up Rome, until finally Galileo was sent for in 1616, his works were put under the ban, and he was enjoined on pain of torture and imprisonment to cease his "heretical opinion." Under duress, he promised never to teach the Copernican doctrine again, and this forced promise he abided by impatiently for fourteen long years.

In the meantime, Galileo's friend Kepler was busily engaged in Germany destroying the Ptolemaic system, if not in as spectacular a manner, yet in a way which struck at its very roots.

Kepler had had troubles of his own. Born in an atmosphere of poverty and domestic bickering, sickly as a child and his eyesight almost ruined through a serious illness, Kepler started life with many handicaps. But he possessed a dogged perseverance and a genius for mathematics which soon won him a number of friends. These aided him in getting to the University of Tübingen, which he entered at the age of seventeen. Here he distinguished himself under the professor of mathematics, Michael Maestlin, who was an ardent supporter of Copernicus and who deeply influenced young Kepler. At twenty-three, Kepler was already installed as professor of mathematics at the University of Grätz.

He now began to speculate about the general plan of the solar system. He knew that there were some glaring discrepancies between the circular orbit theory of planetary motion and the observed facts, and he knew that the six planets then known (Mercury, Venus, Earth, Mars, Jupiter and Saturn) moved

in their orbits at variable speeds and that the farther a planet was away from the sun the more slowly it moved. The way Kepler went about his problem is highly illuminating. Questioning the theory of circular orbits, he tried every conceivable orbit he knew anything about, triangular, pentagonal, hexagonal, and so on, in each instance testing his hypothesis with the observed facts and discarding the hypothesis when he saw it did not fit.

At first, however, he did not have very accurate data to go by, and he published his earlier theories in 1596, thinking the results accorded fairly well with the facts. The effect of the publication was to put him in close touch with Galileo, in then far-off Italy, and to receive an invitation from the greatest astronomical observer of the age, Tycho Brahe, to come to Prague, in Bohemia, and test his hypotheses with the observations there recorded. Kepler accepted the invitation, went to Prague and tested his theories, found they did not accord with Brahe's observations, and unhesitatingly discarded them.

But he had won the friendship and admiration of Brahe, with the result that he accepted an offer to work with him under the patronage of King Rudolph of Bohemia. Here was an unusual combination, a great mathematician working hand in hand with a great observer. To be sure Brahe died soon after Kepler's arrival from Grätz, but the former's wonderfully accurate observations of planetary motion were at Kepler's disposal. Furthermore, as the result of a promise made to Brahe before the latter's death, Kepler himself completed a series of observations he and Brahe had started and published them after considerable difficulties a number of years later under the title of the Rudolphine Tables, in honor of King Rudolph, who had also died in the interim. These tables were of the utmost importance and for hundreds of years served navigators much as the Nautical Almanac of England serves navigators to-day.

Long before the publication of these tables, Kepler had begun to correspond with Galileo, both with respect to the Copernican theory and the construction of telescopes. While Galileo was confounding the ecclesiastics of Italy by breaking through the heavens with his telescope, Kepler was struggling along in a new position at the University of Lenz, in Austria, to which place he had gone after the death of King Rudolph, worries besetting him on every hand. Being short of funds, he had begun publishing an almanac through which he practiced as an astrologer, a practice indulged in by Galileo, and also by other noted men of that period, not to mention the motley crowd who knew nothing whatever of the movements of the heavenly bodies but practiced as charlatans pure and simple.

Kepler's family had been very ill and had almost starved, his salary was in arrears, his mother had been accused of sorcery and had escaped torture only because of his personal intercession, and his efforts to raise money to have the Rudolphine Tables published were meeting with little success. He was hardly in the mood to indulge in laughter at the time his friend Galileo wrote him wishing the two could be together.

But through all his troubles, Kepler kept doggedly on with his speculations as to planetary motion. His earlier theories discarded, he tried others, only to discard these in turn as not according with the facts, until at last he hit upon elliptical orbits with the sun at one of the foci, and, lo and behold, the hypothesis worked! We can well imagine his joy (for the quotation to be given presently indicates that he gave vent to his feelings occasionally), when he applied Brahe's observations and found that they accorded precisely with his theory.

Kepler's great revelation that the planets move in elliptical orbits about

the sun paved the way for his second discovery. He had been puzzled, also, by the variations in the rate at which planets move. Observations showed that a planet does not move with any uniform speed, but moves more slowly at certain times than at others. When near the sun it moves fastest; when farthest away it moves slowest. Applying the same trial-and-error method to this problem, he finally discovered the curious fact that the observed variations in speed are such that planets sweep out equal areas in equal times—which is to say that, if an imaginary line is drawn from the sun to a planet moving in its elliptical path and one end of the line is considered as fixed at the sun while the other end moves with the planet, the quasi-triangular areas swept out by the line in like periods of time are always the same.

Kepler published his first two laws in 1609 in his book on the "Motion of Mars," at the time Galileo was at the height of his fame in Florence. But Kepler was not yet satisfied. There was still another problem which was puzzling him, and this related itself to the periods of the planets, *i.e.*, the lengths of time they take to complete their orbital paths. These periods, it had long since been observed, were not the same for the different planets. The greater the average or mean distance of a planet from the sun the longer does it take to complete its orbit. Was there any exact relationship, Kepler now asked himself, between the average or mean distances of the planets from the sun and their respective periods?

Again, he experimented mathematically. Once more he tried various combinations. He squared the periodic times and the mean distances; he cubed them; he raised them to higher powers—all the while making comparisons to establish a possible relationship. And finally, for a third time, he hit upon a great truth. He discovered that there is an unvarying ratio existing between the mean distances and the periods, *viz.*, the squares of the periodic times (t) of the planets are as the cubes of their mean distances, $(r) - t_1^2 : t_2^2 :: r_1^3 : r_2^3$. In other words $\frac{r^3}{t^2}$ is a constant, or $r^3 = kt^2$. For example, consider the earth's mean distance from the sun as one unit and its period as one year. On the same basis Mars' calculated mean distance from the sun is about 1.5 units. According to Kepler's third law, the earth's period squared is to Mars' period squared as the earth's mean distance cubed is to Mars' mean distance cubed; or $1^2 : x^2 :: 1^3 : (1.5)^3$

$$\frac{1^2}{x^2} = \frac{1^3}{(1.5)^3} \textit{ i.e., } x^2 = (1.5)^3$$

or $x = 1.9$ years, which is the correct period for Mars as borne out by actual observation.

Kepler published his third law in 1619, at which time he wrote regarding it in the following words:

> That for which I joined with Tycho Brahe, for which I settled in Prague, and for which I have devoted the best part of my life to astronomical contemplations, this at length I have brought to light. It is not eighteen months since the first glimpse of light reached me, three months since the dawn, very few days since the unveiled sun, most admirable to gaze upon, burst out upon me. Nothing holds me; I will indulge in my sacred fury; I will triumph over mankind by the honest confession that I have stolen the golden vases of the Egyptians to build up a tabernacle for my God, far away from the confines of Egypt. If you forgive me, I rejoice; if you are angry, I can bear it; the die is cast; the book is written; to be read either now or by posterity, I care not which; it may well wait a century for a reader, as God has waited 6,000 years for an observer.

In writing as he did, Kepler realized full well that the ban of the church would be upon his revelations, for, three years before, the College of Cardinals had suppressed his other writings with those of Copernicus and Galileo. But the arm of the church could not reach Kepler in Austria as easily as it could

Galileo in Italy, and so his person was safe. How he regarded his critics is well summed up in what he wrote on a previous occasion:

> If any one be too dull to comprehend the science of astronomy, or too foolish to believe in Copernicus without prejudice to his piety, my advice to him is, that he should quit the astronomical school, and condemning, if he will, any or all the theories of philosophers, look to his own affairs, and leaving this worldly travail, go home and plough his fields.

Kepler's contributions to astronomy were indeed great. The discovery of any one of his three laws would have been sufficient to give him lasting fame; but he did not stop there. In the course of bringing the Rudolphine Tables to completion (they were not published till 1627), he incorporated his new discoveries and set down the observed facts regarding the planets in such a manner that their locations could be easily computed far in advance. In addition, he came nearer to estimating the true distance of the earth from the sun than any astronomer since Hipparchus had done; he made a profound study of comets, and his explanation of why their tails point away from the sun is almost identical with that accepted to-day; and the prodigious amount of tedious computing he did, without logarithms or modern tabulating devices, is almost beyond comprehension. Napier, the inventor of logarithms, was a contemporary of Kepler, but his invention came too late to benefit the latter very much. When Kepler heard of the invention, however, he was enthusiastic over its possibilities, adding that logarithms would triple the life of the astronomer.

It is difficult for us to conceive how startling the discoveries of Kepler must have been in his own day. That planets move in circular orbits was a deeply rooted belief, handed down from the ancient Greeks and accepted unquestioningly even by Copernicus. Elliptical orbits was a most revolutionary idea even to Galileo, who was quick to accept it, however, and make use of it in his lectures against the Ptolemaic system, as soon as Kepler had set forth his proofs.

Kepler died in 1630, soon after the publication of the Rudolphine Tables. The same year, after fourteen years of enforced silence, Galileo published his great work on the Ptolemaic and Copernican systems, written in dialogue to conform with the spirit of his promise to the ecclesiastical authorities. The book immediately created a tremendous stir, and, although it was later suppressed and Galileo was forced to recant to save his aging body from torture and for a few more years of research, the mischief had been done. The new knowledge spread throughout Europe. The demolition of the Aristotelian cosmogony was complete. Between them, Kepler and Galileo had placed astronomy on a secure scientific basis, from which it could proceed to perfect its principles.

But it was not only the Aristotelian view of the universe that was crumbling during this period. The authority of Aristotle in biology and physics was likewise being swept aside. Kepler and Galileo did not stand alone. Contemporary with them, Gilbert in physics and Harvey in biology were shattering the Aristotelian tradition.

Galileo, as has been noted, was disconcerting the Aristotelians not merely in the field of astronomy but in that of physics as well. Both he and Kepler advanced the study of optics. The latter worked out the principles underlying the refraction of light through various media, such as air and glass, to the point from which the laws of refraction were later derived (by Snell), while Galileo worked out many of the important principles underlying lenses in addition to perfecting the telescope. He also invented what was probably the first thermometer, and began the quantitative study of heat.

In dynamics, a most important department of physics, Galileo's contributions equalled in importance his work in astronomy. Following his famous experiment with falling bodies at the leaning tower of Pisa, which so antagonized his colleagues and others that he was forced to give up his professorship at the university there, Galileo worked out the laws of falling bodies now familiar to every schoolboy. He had noticed that a falling body does not descend at a uniform speed, but that its velocity increases as it falls and that the longer the time during which it falls the greater does its velocity become. So he set about trying to find a definite mathematical relationship in falling bodies between time of fall, speed and distance, just as Kepler had faced the problem of the relationship between planetary orbits, distances and periods. Galileo made a number of interesting experiments with balls rolling down inclined planes, taking care to minimize the effects of friction and constructing an ingenious yet simple timing device. After collecting sufficient data he applied his mathematics and found that the observed increase in velocity when a body falls is directly proportional to the time of falling, *i.e.*, the ratio of the velocity (V) to the time ("t") is a constant—$\frac{v}{t} = K$ or $V = Kt$. From this he derived, as a simple corollary, that the distance of descent ("d") is always proportional to the square of the time of falling. Take a body falling from rest, for example: Distance traveled equals the average velocity multiplied by the time, and if the velocity is constantly increasing, the average, starting from rest, is $\frac{\text{"O + V"}}{2}$. Hence $d = \frac{(O+v)}{2} \cdot t$, or $d = \frac{vt}{2} = \frac{Kt \cdot t}{2} = \frac{1}{2}Kt^2$, *i.e.*, the distance of fall varies as the square of the time.

As in the case of Kepler's laws, Galileo did not explain *why* these ratios must be so. He merely stated the facts. It took Newton in the next generation to explain both Kepler's and Galileo's discoveries. With respect to the foregoing equation, it was later shown that "K" is the value of the force of gravity at the earth's surface. The significant point here is that Galileo's work in dynamics swept aside the misconceptions of Aristotle regarding falling bodies and laid a secure foundation upon which future scientists could build. Galileo also worked out mathematically that the path of a projectile, which gunners had long since recognized as deviating from a straight line, is a parabolic curve and that there is a direct inverse relationship between weight and distance when bodies are acted upon by a given force, *e.g.*, a force that will move a two-pound weight through one foot of distance will move a one-pound weight exactly two feet or a half-pound weight exactly four feet.

In concluding this brief sketch of the most important of Galileo's contributions to physics, it is fitting to recall that, when at the age of sixty-nine he saved his body from the torture rack and the flames to which an ecclesiastical despotism stood ready to consign him unless he recanted with respect to his astronomical teachings, he was undoubtedly preserving himself for the uncompleted work on dynamics and statics he had started over forty years before at Pisa. It was during these last years that he finished his experiments. Under the watchful eyes of the clerics, a virtual prisoner, and with failing health, the great Galileo had passed seventy when he prepared to hurl his last thunderbolt into the ranks of bigotry and authority. Under tremendous handicaps, he published in 1636 the now famous "Dialogues of Motion." The devastating effect of this great work on preconceived ideas was not appreciated at once by the clerics, but it apparently had struck home by the time of Galileo's death six

years later, for he was denied decent burial, all his manuscripts were seized and most of them were burned, and even his will was vigilantly scrutinized and disputed.

Happily, Galileo's older contemporary in physical advance, William Gilbert (1544–1603), was born in England and not under the eyes of Rome. For England in Gilbert's day had become quite tolerant as compared with the England of Roger Bacon's day. Gilbert thus escaped persecution, although his researches in electricity and magnetism met with the same type of bigoted opposition as did Galileo's in mechanics. How the first great man of science in England since Roger Bacon regarded his opponents is well expressed in the preface to his monumental work, "De Magnete," published during the year of Bruno's martyrdom in 1600:

> Why should I submit this noble science and this new philosophy to the judgment of men who have taken oath to follow the opinions of others, to the most senseless corrupters of the arts, to lettered clowns, grammatists, sophists, spouters, and the wrong headed rabble, to be denounced, torn to tatters, and heaped with contumely! To you alone, true philosophers, ingenuous minds, who not only in books but in things themselves look for knowledge, have I dedicated these foundations of magnetic science.

How his bold stand for observation and experiment must have rankled in the minds of the guardians and protectors of the written word!

Gilbert was educated at St. John's College, Cambridge, evidently specializing first in mathematics and later in medicine. He received the degree of M.D. in 1569 at the age of twenty-five. Following the custom of educated men of the day, he now spent a few years in travel on the continent, visiting Italy, then the intellectual center of the world despite its religious intolerance. He settled down in London to practice medicine in 1573, and soon established a wide reputation both as a physician and as an experimentalist along chemical, electrical and magnetic lines, his home becoming the rendezvous for a group of admirers and followers who watched his experiments and accepted his conclusions. His fame reached its height during the year the "De Magnete" was published, in 1600, when he became president of the Royal College of Physicians and chief physician to the court of Queen Elizabeth. He died three years later.

Gilbert discovered some of the outstanding facts which form the basis of modern electricity and magnetism, and he was the first to distinguish between electrical and magnetic phenomena. He discovered that the earth is a giant magnet and he invented the term "pole" to explain certain of the observed facts. He was also the first to distinguish between substances that can be electrified by friction and those that can not. These contributions will be taken up again later when we get to the more constructive developments that grew out of Gilbert's pioneer work.

Great as were Gilbert's contributions, his greatest service undoubtedly lay in clearing away some of the weeds of misconception which had grown up about the subjects of electricity and magnetism since ancient days and which constituted a part of the Aristotelian dogmas of his period. This service was all the more valuable since alchemy, astrology and magic were all involved in the misconceptions Gilbert attacked, and, until they were cleared away, little progress along the lines of chemistry as well as in the field of electricity and magnetism could be expected.

The phenomena of magnetism had long been mixed up with magical practices. As Gilbert says, "the lodestone was accused of producing melancholy, of making love philters, of losing its power when rubbed with garlic, and regaining it when smeared with goat's blood, of de-

clining to attract iron in the presence of diamond." Applying the test of rigid experiment to each of these statements in turn, Gilbert demonstrated them to be so much hocum. It had been taught that a piece of iron rubbed with a diamond becomes magnetized. Gilbert proceeded to find out if this is true. As he says farther:

> We made the experiment ourselves with seventy-five diamonds in presence of many witnesses, employing a number of iron bars and pieces of wire, manipulating them with the greatest care while they floated in water, supported by corks; but never was it granted me to see the effect mentioned.

It had been held for 2,000 years that amber alone can be excited by friction to attract other bodies. Gilbert dispelled this notion and demonstrated that many substances can be thus excited, among them glass, sulphur and resin. It had been known for thousands of years that a compass needle always points in a certain direction and many had been the speculations advanced to explain this phenomenon. Gilbert's discovery that the earth is a magnet with "poles" at the north and south furnished a simple explanation of both compass direction and dip. In this connection, he remarks in his book:

> The common herd of philosophers, in search of the causes of magnetic movements, called in causes remote and far away. Martinus Cortesius . . . dreamt of an attractive magnetic point beyond the heavens, acting on iron. Petrus Peregrinus holds that "direction" has its rise at the celestial poles. Cardan was of the opinion that the rotation of iron is caused by the star in the tail of the Ursa Major. The Frenchman Bossard thinks that the magnetic needle turns to the pole of the zodiac. . . . So has ever been the wont of mankind: homely things are vile; things from abroad and things afar are dear to them and the object of longing.

Gilbert cleared away much of the underbrush and in doing so emphasized anew the value of observation and repeated experiment as the basis of scientific investigation. As expressed in his own words and quoting again from his treatise:

> In the discovery of secrets and in the investigation of the hidden causes of things, clear proofs are afforded by trustworthy experiments rather than by probable guesses and opinions. . . .
>
> Whoever wishes to try the same experiments, let him handle the substance, not carelessly, but prudently and deftly, and in the proper way, and when the thing does not succeed let him not in ignorance denounce my discoveries, for nothing has been set down in these pages which has not been many times performed and repeated.

It would be going too far afield to indicate the innumerable ways in which Gilbert's "De Magnete" shattered existing notions regarding electrical and magnetic phenomena and laid the foundation for a better understanding of scientific truth. It is a good book to dip into. It contains many quaint and humorous as well as illuminating passages. When Galileo had seen it, he expressed his opinion about Gilbert enthusiastically:

> I think him worthy of the greatest praise for the many new and true observations which he has made, to the disgrace of so many vain and fabling authors, who write not from their own knowledge only, but repeat everything they hear from the foolish and vulgar, without attempting to satisfy themselves of the same by experience.

Gilbert did not possess the depth and scope of Galileo, nor did his work affect progress as immediately, but he nevertheless contributed in important ways to scientific advance.

While Gilbert was at the height of his fame in London, a young contemporary, destined to strike at the citadel of authority from another quarter—also an Englishman and also interested in medicine as a career—had journeyed to Padua to complete his medical training under the renowned surgeon and anatomist Fabricius. This was William Harvey (1578–1657), the celebrated discoverer of the circulation of the blood.

Like Gilbert, he became prominent as a physician in London and served royalty, first as physician to James I and later to Charles I. Harvey's contributions to scientific advance were in the field of biology.

Again, the great influence here was in breaking down the bars of unquestioning authority, and in this respect Harvey was considerably aided by the work of two outstanding predecessors, Valerius Cordus (1515–1544) and Andreas Vesalius (1514–1564), one a German and the other a Belgian.

Cordus was a botanist and the son of a botanist. In his day the relation of botany to medical practice was intimate, since the latter utilized herbs and plant products very extensively. Hence every physician was a botanist and every botanist a physician. It will be remembered that Dioscorides in the first century had written a medical botany, which because of its practical aspects had come to overshadow the earlier and better work of Theophrastus. By the fifteenth century Dioscorides was giving place to Theophrastus and with the coming of the youthful genius Cordus (who did all his work before he was 29), the still further step was taken of describing plants anew from nature instead of placing any dependence at all on the incomplete descriptions of the ancients. Cordus lectured at Wittenberg, in Germany, where he taught men to break away from the past and think for themselves. He wrote a notable work on plants, was an excellent first-hand observer and explored the botanical riches of Germany to good practical effect. In 1542 he visited Italy on a botanical expedition and died prematurely in Rome before his work was completed. He left his imprint on botanical advance in both Germany and Italy.

Vesalius, the other important predecessor of Harvey, was born at Brussels and received his medical education at the most renowned universities of France and Italy. He had a distinguished public career as a physician, serving as army surgeon in Flanders, then as professor of surgery at Padua and other universities, later as court physician to Charles V, and still later as court physician to Philip II at Madrid. He made a pilgrimage to Jerusalem in 1563 and died on the voyage home.

The great work of Vesalius lay in the biological field of anatomy. His writings on the structure of the human body have been likened by a noted historian to the discovery of a new world. Vesalius broke away from Galen, who had held undisputed sway in anatomy and physiology for fourteen centuries, and attempted to place anatomy on the firm basis of exact observation. In differing from Galen and in indicating his disgust with the crude dissections of his day, he secured the enmity of many of his fellow-physicians, but at the same time he gathered a number of followers to himself who faithfully carried on his work.

It was the influence of Vesalius which Harvey felt on arriving at Padua a half century later. Vesalius had broken with the Galenic tradition in anatomy. Harvey set himself the task of doing the same for physiology. He was not satisfied with Galen's ideas about bodily functions. In fact, no rational understanding of the dynamics of the human system was possible as long as one accepted the conclusions of the Galenic school that the arteries are filled with air. This false notion arose because the arteries are found to be empty after death.

During the early part of his medical practice in London, Harvey was appointed in 1615 as lecturer on anatomy at the College of Physicians. Here he started his carefully planned and ingeniously executed experiments which led to the discovery that the blood actually flows in a circle from the heart through the arteries and veins back to the heart again. He began teaching this

doctrine in 1619 and immediately aroused a storm of opposition from the medical fraternity. The storm raged for twenty-five years before the truth of his discovery was recognized, and in the meantime (in 1628) he published a tract on the subject which fortified his contentions with the most solid and convincing proofs. His own statement regarding his discovery, made in his tract, is of considerable interest:

> I frequently and seriously bethought me, and long revolved in my mind, what might be the quantity of blood which was transmitted, in how short a time its passage might be effected, and the like; and not finding it possible that this could be supplied by the juices of the ingested aliment without the veins on the one hand becoming drained, and the arteries on the other hand getting ruptured through the excessive charge of blood, unless the blood should somehow find its way from the arteries into the veins, and so return to the right side of the heart; I began to think whether there might not be a motion, as it were, in a circle. Now this I afterwards found to be true; and I finally saw that the blood, forced by the action of the left ventricle into the arteries, was distributed to the body at large, and its several parts, in the same manner as it is sent through the lungs, impelled by the right ventricle into the pulmonary artery, and that it then passed through the veins and along the vena cava, and so round to the left ventricle in the manner already indicated. Which motion we may be allowed to call circular.

But it must not be thought that all Harvey's conclusions were equally sound. He accepted Aristotle's assumption that many forms of life arise through spontaneous generation, and in 1651 published a treatise in which he laid the foundations for the so-called epigenesis theory of development, both of which assumptions were later proved to be false. Besides his famous discovery, his main contributions lay in breaking away from the ancients in other important respects and in emphasizing the need for first-hand observation and experiment.

With Cordus, Vesalius and Harvey, three important branches of biological study (botany, anatomy and physiology) became freed from the thraldom of authority and the ground was made ready for a further advance. But many misconceptions were still rife and others were to follow. In this field and in others, new fallacies came to be accepted as fast as the old ones were swept away, for the reason that the foundation stones had not yet been securely laid. Other great scientists were still to come and place physics on as secure a basis as Kepler and Galileo had placed astronomy, and the ancient Greeks had placed mathematics, and until then chemistry and geology and biology and finally psychology were still speculative at bottom.

The significant thing about the whole period here under consideration is that, in addition to the solid establishment of astronomy as a science, the blind acceptance of Aristotle's results (whether true or false) had come to an end and that his methods of observation and experiment, a return to which Roger Bacon three and a half centuries before had pleaded for in vain, were finally being revived. The critical angle from which Aristotle has been viewed in this article should not result in obscuring his great contributions, despite the grievous mistakes he made. It was the impossibility of separating the true from the false in Aristotle's writings, since the blind adherence to the written word forced the acceptance of the false with the true, which fettered progress. But the fetters had now been removed by a return to direct observation and experiment.

BIG GAME OF THE UNITED STATES AND ITS CONSERVATION

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At the time of the discovery of North America, large game in abundance ranged nearly throughout the length and breadth of the continent. Deer of several kinds, browsing largely on the leaves of tender shrubs and craving shelter, lived in the forests everywhere, except in the far north. Great herds of grass-feeding animals, buffalo, antelope, elk and mountain sheep occupied the open plains or high mountains of the West. Moose, even more than the deer, were restricted to the forests, and bears were numerous wherever conditions were suitable.

With the appearance of the settlers, the clearing of the forests for farms and the occupation of the grass lands for agricultural purposes or the grazing of domestic stock, the disappearance of much of the game was inevitable. The final passing of the buffalo could not have been prevented, for great herds of buffalo have no place, as game, under modern conditions. Inevitable also was the passing of most of the antelope, originally more numerous perhaps than the buffalo.

Pressure of human occupation, therefore, together with unrestricted killing by hunters, inroads by predatory animals and other incidental factors, led to the disappearance of the game, or to its reduction to comparatively small numbers over most of its former range. Deer and moose, however, are now increasing, where accorded protection, especially on some of our national forests and national parks, which may be regarded as great natural reservoirs for game. Mountain sheep still occur in places in the higher mountains of the west and in the desert ranges of the southwest, usually in small bands, which as a rule show little or no increase, although no killing is permitted under the laws of most states. The antelope, regarded by many as the most beautiful and characteristically American of our game animals, have decreased very rapidly, especially in the past ten years. They still occur in sixteen states, many of the smaller groups unfortunately in sections where their extinction is practically certain because of local conditions. Antelope are not likely to survive except on areas where they are accorded special protection. In the west the elk, accustomed to summer largely in the mountains, and to migrate to wintering areas on the lower mountain slopes and the surrounding plains, have been forced back to winter in the higher and more inaccessible mountains. While thousands still remain in the Rocky Mountain section, chiefly in and around Yellowstone Park, and in the mountains nearer the Pacific Coast in Washington, these are mere remnants of the former great herds.

Although the general outlook may seem rather discouraging, progress is being made and much may yet be done, not only to save the remnants, but to greatly increase numbers and restore game to sections from which it has dis-

appeared. In order to deal intelligently with the problem we must first understand and consider the requirements of the game and all the factors that may result in decreases or increases in number.

The importance of establishing game preserves, national, state, municipal and private, is becoming more generally recognized; but these must be suitably located and properly administered in order to achieve their highest usefulness. The ideal game preserve is a protected area favoring the rapid increase of game within its borders and from which the surplus can readily spread and stock surrounding areas. More game preserves are urgently needed on national forests. The national parks serve as great game preserves in which no hunting is allowed.

Among the requirements of game, the one of prime importance is sufficient palatable food during the winter as well as during the summer. In many regions summer range is ample, but the game is forced by deep snows to migrate to lower levels, where winter range and forage are inadequate, and where suffering and starvation result. This is well exemplified by the elk of the Yellowstone Park region, to which reference has already been made. Especial interest attaches to these elk, as they constitute the only really large herds of big game remaining in the United States, exclusive of Alaska; and they suffer pitifully, many dying from starvation in hard winters. The Izaak Walton League of America is issuing appeals, largely through its journal *Outdoor America*, for funds to be raised by popular subscription and devoted to the purchase of forage-producing lands, to be added to the present inadequate winter refuge in Jackson Hole, Wyoming, where thousands of elk concentrate every winter.

On the other hand, game may become too numerous on certain limited areas whereby the preferred forage plants are destroyed and the number of animals that can be permanently maintained is correspondingly reduced.

The extent of the destruction of game by large predatory animals, mountain lions, wolves, coyotes and bobcats in the western states is not generally realized. Some nature-lovers deplore the systematic killing of predatory animals that prey upon livestock and game and maintain that the balance of nature is thus upset. The hypothetical balance existing at the time of the discovery of America, meaning a stabilized condition under which the numbers of the predatory animals and the game upon which they preyed were about stationary, was, however, long ago completely overturned and can never again be restored.

This is due, as we have seen, to the progressive occupation of the country by civilized man. When we remember that to the onslaughts of predatory animals were added unrestricted killing by men armed with guns, and the driving out of game incident to the clearing of forests and the pasturing of domestic stock, it is not surprising that the game decreased rapidly in numbers. As game decreases the attacks by predatory animals left uncontrolled are concentrated on the survivors, which are thus threatened with complete extermination.

The large predatory mammals—mountain lions and wolves—require for their sustenance animal food in large quantities. Owing to this compelling need, coupled with abundant power to kill, their preference is for large game, as shown by studies of food habits. Hunters on certain game ranges in the west find that stomachs of mountain lions examined usually contain the remains of deer; and it is estimated that on such ranges a single mountain lion probably kills from fifty to one hundred deer each year. In the absence of the lion, sport might have been afforded to fifty to one

hundred hunters who, in killing a deer each, would have benefited by the hunt and would have put to economic use the meat otherwise wantonly lost.

The effective control of the small prairie wolves, or coyotes, is a difficult problem in game protection. They are peculiarly favored by their size, which is small enough to enable them to escape easy detection, and to subsist upon game birds, rodents and other small animals; and yet they are large and powerful enough to constitute a very serious menace as large game and stock killers. Many young deer, calves and sheep especially become their victims.

As nature lovers we are loath to contemplate the destruction of any species, but as practical game conservationists we are forced by the records to the conclusion that the large predatory animals must be reduced to very small numbers if game is to show a satisfactory increase. In various parts of the west, where through systematic efforts most of the large predatory animals have been removed, there has followed a marked increase in deer and other game species.

The success attending recent efforts to restock with deer forested areas in some of the eastern states is doubtless due, in part, to the general absence or scarcity of large predatory animals.

The greatest predatory animal after all, however, is man; and while we can not reduce his numbers, some control must be exercised over his too indiscriminate use of modern firearms, if a sufficient breeding stock of big game is to be maintained. But this does not mean that hunting under proper conditions should be discouraged. The joy of the chase provides wholesome recreation of a kind which can be obtained in no other way, and which perhaps only a hunter can fully appreciate. Some maintain that hunting is cruel, especially as it may bring suffering to the wounded, and urge that predatory animals should be allowed to kill the surplus game. Such advocates are presumably unfamiliar with the frightful methods of predatory animals, which may begin devouring the weak and helpless while still alive, their agony being thus greatly prolonged. It should be remembered that most game animals come to a tragic end. The mortality rate from predatory animals is especially high during the first year. If they escape the hunters, declining vigor eventually increases the danger from carnivores until finally they are pulled down, mauled and killed.

Much information is accumulating concerning all the conditions affecting game, but there is an insistent demand for more exact scientific knowledge to serve as a basis for successful game administration. To maintain the game supply, and at the same time to provide, if possible, fair sport for the increasing number of hunters that may confidently be expected is the problem before us. Fortunately, appreciation of the recreational and economic value of game has become more general during recent years, and the demand more insistent for its protection and increase. Through the efforts of game protective associations and individual conservationists a more enlightened public opinion is resulting in better federal and state laws and measures for their enforcement. Much remains to be done, however, to enlist the interest and local aid of the people everywhere, as without their cooperation laws are ineffective and the protection of game becomes extremely difficult, if not impossible.

It has been the practice in many states to issue hunting licenses for the open season to all comers, with too little regard for the available game supply of any particular area. The hunters may far outnumber the animals hunted within a given section, and under such

conditions, long continued, the extinction of the game is inevitable.

The killing of too many animals may be prevented by adopting a limited-license plan, based on annual estimates of game conditions in each district. This means that the number of big game licenses issued for a given area in one season would depend upon the number of game animals which it has been determined in advance can be spared.

This is proper game administration, but it presents some difficulties in actual practice, for the reason that many persons desiring to hunt may be refused licenses. Another plan for limiting the number of game killed, more uncertain in its results, but sometimes more popular, is to issue licenses to all applicants, limiting the open season, however, to a short time instead of the considerably longer period that might be allowed. The important point is to maintain numbers without the necessity of establishing year-long close seasons, except on game ranges being restocked.

There is an urgent need for a better understanding of the fundamental principles of practical game administration, which may be briefly stated. It should be remembered that the potential rate of increase for any species of animal would, if unchecked, force all others out of existence. A high mortality rate is a biological necessity. Any failure of game to increase in a given section of the country is probably due to one or more of three reasons: (1) There may be insufficient suitable food, water or shelter; (2) too many game animals may be killed by predatory animals or by hunters; or (3) animal diseases, frequently epizootic, may be present.

The number to be maintained on a given area should be the largest that can be supported without reducing the food-producing capacity, due consideration being given to the reasonable demands for grazing of domestic stock and of any other local interests. All surplus should be removed, ordinarily through hunting.

Hunting as a sport attracts men to the forests and mountains, where for a brief period they may escape the artificial life to which most are confined. From such an outing they return to their usual duties, improved mentally and physically, with a broader outlook and with a finer appreciation of natural resources which we can not afford to sacrifice.

SCALE INSECTS[1]

By HAROLD MORRISON

BUREAU OF ENTOMOLOGY

WE hear so very much about the destructiveness of those little creatures known as insects that we are apt to overlook the fact that some of them are very useful to us. Thus, the one family of the scale insects or coccids includes within its numbers more different kinds of insects that are or have been of use to the human race as food or in the arts and industries than does any other corresponding group.

Two forms, referred to in the Bible or by ancient writers such as Pliny, are believed to be scale insects, although there has been some debate as to the particular insect referred to in each case. One of these, living on tamarix trees in the mountains of the Sinai peninsula, is credited with having furnished the manna which supported the Israelites at one period of their migration from Egypt back to the Holy Land. This manna occurs as a thickened, sweetish liquid, somewhat resembling honey, which forms in large hanging droplets on the branches of the tamarix trees as a result of the active feeding of many scale insects. The other insect, whose usefulness has been recognized and described since very early times, is known as the oak kermes and is found on only one certain kind of oak. It supplied to ancient manufacturers a crimson dye which was quite probably the royal purple of the early writers, since this color is at present believed to have been a shade of red rather than the mixture of red and blue which we know to-day by the name purple. Two other related scale insects, living on the roots of grass and other plants, one in Poland, the other in Armenia, also formed important sources of red dye, at least during the Middle Ages and up to the period following the discovery of America by Columbus.

With the conquest of Mexico, soon after 1500, Europeans first became acquainted with that best known of all the useful coccids, the cochineal insect. With its value fully recognized and its place in the highly developed Aztec civilization of that region well established, this insect soon became an important article of commerce for the Spanish traders, so important, indeed, that when the Spanish monopoly in Mexico was broken up after 1800 by the revolution and declaration of independence of that country, the industry of producing the commercial form of the insect for the market was successfully established in the Canary Islands, after attempts to grow it commercially in various parts of Spain and the other sections of the Mediterranean region had proven unsatisfactory.

An interesting sidelight on the history of this insect shows clearly the difficulties that may develop when accurate knowledge of any living form is lacking. This is the story of the attempt to establish its culture in India. Living examples, believed to be of the true cochineal insect, were sent to India from Brazil, were rather widely distributed there, and became well established

[1] Broadcast from Station WRC, Washington, October 29, 1925, under the auspices of the Smithsonian Institution and the direction of Mr. Austin H. Clark.

on previously introduced cactus plants. The development of an industry was encouraged as much as possible, but it was found that some three times the quantity of the East Indian cochineal was required to supply the same amount of dye that a given quantity of the Mexican insects supplied. This, coupled with gradually falling prices for the product, soon caused the complete failure of the industry in India. With our present-day knowledge of the insect and its relatives, we know that these early introductions into India were not true cochineal insects, but were instead one of its wild relatives, smaller in size and so deficient in coloring matter as to doom to failure in advance the attempt to establish a cochineal industry with them.

To-day, due to the tremendous strides that have been made in the production of manufactured or synthetic colors, the coal tar dyes and others, none of the insect dyes can be regarded as commercially important, although a certain quantity of the cochineal insect is still gathered annually in the Canary Islands.

However, there is another scale insect which has not only maintained but has actually greatly increased its commercial importance in recent years. This is the so-called lac insect, from which is obtained the shellac and other commercial lacs, substances having, either in their natural or in their bleached condition, a long list of important industrial uses, taking a part in the manufacture of phonograph records, the preparation of many paints and varnishes, the making of sealing wax and special printing inks, as an insulating material in many kinds of electrical work, for the manufacture of imitation ivory articles, such as toilet articles and poker chips, in some kinds of shoe polish, and so on.

While it has some close relatives on desert plants in the southwestern United States, the true lac insect is a native of India. There it is grown on a number of different kinds of trees, usually as an adjunct to the growth of cultivated field crops. At certain times each year the young insects swarm over the younger branches of the trees on which they live, but soon settle down on these branches in such numbers that when they begin to feed and to give off the protective secretion which very shortly covers them, this secretion eventually so increases in quantity and spreads to such an extent that the individual masses become fused, surrounding each twig, together with the insects feeding on it, with a cylinder of secreted matter, sometimes several inches long, which is the lac. When the enclosed insects are full grown and have finished giving off the lac, the twigs are cut off, giving the stick lac, which, after a rather intricate manufacturing process that results in the elimination of the wood, the bodies of the insects and other organic matter, becomes the highest grade product, shellac, or the lower grade products, button lac, seed lac, garnet lac and others. These are the commercial forms in which the product is shipped to all parts of the world for manufacturing purposes. The total production varies greatly from year to year, according to the demand, but averages around forty million pounds per year, nearly half of which is said to come to the United States.

In this country, scale insects are unquestionably best known as enemies of cultivated plants, shrubs and trees. Due to their intimate association with the plants on which they live, and their generally small size and inconspicuous appearance, they have unwittingly been distributed very widely over the country, and even over the world, by the very people most interested in escaping the damage resulting from their attacks, that

is, by those individuals who were attempting to establish commercial fruit-growing and related industries in new localities.

A brief history of the spread of one of these, the notorious San José scale, may serve to illustrate the way in which an insect may become a pest, and to emphasize the potential dangers lurking in any insect found living on cultivated plants. This insect, probably more than any other single pest, has served to bring home to every one interested in growing plants the great importance of the factor of insect damage in agricultural production.

Although certainly brought to the United States from some other country, probably China, the insect was first discovered in 1880 near the town of San José, in California, whence it spread in the next few years through adjacent local territory and the other Pacific coast states, without attracting much attention, except among those who realized its capacity for damage. It was only after the discovery, more than ten years later, that it had been brought to the eastern part of the country on fruit trees desired for experiments in developing new varieties resistant to the attacks of another insect pest, the plum curculio, and the further discovery that it had quickly become widely distributed and very injurious, due to the introduction of infested nursery trees into many orchards throughout the eastern states, that the insect began to attract the almost universal attention which it ultimately compelled. Subsequently, as the demand for commercial fruit production has arisen in other regions, with the resulting introduction of fruit varieties from the older fruit-growing countries, the insect has appeared in Chile, in South Africa, in Argentina and in northern India. Only the countries of Europe, as a result of the application of stringent prohibitive measures regarding the introduction of plants infested with this insect, and possibly with the assistance of a somewhat less favorable climate, have been successful in avoiding its ravages.

The immediate recognition by the entomologists of the Department of Agriculture of the serious menace to horticulture created by the establishment of the San José scale in the eastern states did result beneficially in one important respect, but at a price which takes toll annually in most sections where fruit is grown commercially. Since the natural enemies of this scale—the tiny parasites and the predatory insects which might devour whole colonies—were obviously too few and too little important to be of service in its control, numerous experiments were undertaken by the department and by the state experiment stations to discover chemical compounds which could be applied to infested trees without injury to them, but with deadly effect on the insects. Of the many which were tried, the few best were developed by further experiments with the aim of greater effectiveness at lower cost, and are, even to-day, being continually worked on and improved as additional knowledge of chemistry and physics and a better acquaintance with the habits of the insect point the way. The net results are that the grower is no longer confronted with the prospect that his orchards may be destroyed in spite of his best efforts to the contrary, while the consumer is able to make his choice from more perfect fruits than were ever available in the past. Besides this, the successful application to other injurious insects of the principle of control by the use of so-called insecticides was greatly stimulated by the results obtained in the fight against the San José scale.

What are scale insects? The scale insects and mealy bugs, or coccids, are

closely related to the plant-lice, and, with these, are familiar annoyances to every one who has ever maintained a garden or raised a fruit tree. All these groups have one characteristic in common, that of obtaining their food from the plant on which they live by inserting a long slender tube in its tissues and sucking up through this the juices of the plant. But otherwise, as they occur in nature, they vary so greatly among themselves, both in appearance and in habits, that it is difficult to believe that they really have that close relationship which scientific studies have shown to exist between them.

Most of the common plant lice are small, naked, soft-bodied insects, about one twelfth to one sixth of an inch in length, with slender legs and more or less pear-shaped bodies colored in various shades of yellow, green, red and brown to black, and often marked or spotted in characteristic patterns. Two pairs of delicate wings may be present, but are more often lacking. Many of these insects live the greater part of their lives hidden away in curiously formed galls on their host plants. The scale insects present a much greater diversity in size and appearance, some, when full grown, appearing no longer than one fiftieth of an inch, while others, such as some of those which are found in tropical regions, reach a length of more than one inch. Some, such as the mealy bugs, have soft bodies concealed and protected by a dense coating of white powdery wax or by a sac of similar material; others are naked but have the outer surface much thickened and hardened to form a protective layer; still others, the true scale insects, these including some of the worst enemies of fruit and shade trees, are tiny, flattened, without legs, and are completely concealed beneath a slightly elevated, scale-like covering made up of cast skins and secretions from the insects' bodies. This covering scale varies greatly in appearance according to the species, some being round, with a tiny conical hump in the center, some oval, some pear-shaped, some resembling the shell of an oyster, and some so very long and slender as to suggest a short piece of thread lying on a leaf. The shape of the tiny insect lying beneath the scale likewise varies much as does that of the scale itself.

These descriptions apply only to the females. The males, where they are known, are small, delicately constructed insects, with long feelers, the usual six insect legs and generally a pair of delicate wings, but with no means of obtaining food, in fact differing so widely from their much larger, fat-bodied, but degenerate female relatives that their relationship would never be suspected without a careful study of their habits.

MEN WHO HAVE EXPERIMENTED ON THEMSELVES

By Professor FRASER HARRIS

LONDON, ENGLAND

THE medical man in the course of his professional duties runs more than the ordinary risks of infection. But he accepts these as incidental to his profession just as the sailor and the soldier accept the risks in theirs.

In the bad old days before the discovery of anti-diphtheritic serum that has reduced the mortality in diphtheria from about 90 per cent. to a very small figure and quite taken the terror from that dreadful disease, the physician ran very great risks in attending a case of diphtheria. Quite often he had to open the wind-pipe to prevent the child being suffocated by the "membrane" that formed over the glottis; and while doing this the child might cough in his face; in a short time he too had diphtheria and not rarely he went home to die.

If "peace hath her victories no less renowned than war," then certainly war has no monopoly of courage.

In the earlier days of the use of the X-rays, before the extent of their tissue-destroying properties was known, several medical men received severe burns from the rays, some had to have a hand or an arm amputated, and one or two lost their lives.

Researchers into medical problems have used their own bodies more frequently than one would think who has not specially noted the fact. Those who work with the microscope have of necessity to use their eyes so long at a time that they are apt to suffer from inflammation of the eyes.

The discoverer of the capillaries—the first man to see the blood moving in these minute tubes—Marcello Malpighi, so strained his eyes that they were painfully inflamed for long periods. He is rightly called "the father of microscopical anatomy," for he made out important minute structures in the skin, lung, spleen and kidney with which his name has ever since been associated.

The outstanding martyr of microscopy is the young Dutchman, Jan van Swammerdam. He worked on the minute structure of the internal organs of insects; and so incessantly for months at a time that not only his eyesight but his general health suffered seriously. Having no artificial light capable of being used with the microscope, which indeed at that date (1660) was but a dissecting lens, he had to work in the direct sunshine and of course only during the day.

"If he desisted at noon," says his biographer, "it was only because the strength of his eyes was too much weakened by the extraordinary efflux of light and the use of microscopes to continue any longer upon such small objects." Swammerdam, who died in 1680, and had graduated doctor of medicine at Paris but never practiced, was the first to describe the minute structure of the may-fly and of the honey bee.

A friend of the author's, a distinguished Scottish pathologist, so injured his eyes with application to the microscope that for many months he could not use them at all. He had been trying to get a glimpse of the excessively transparent parasite of syphilis discovered by a German scientist only a short time before: he verified the discovery.

Laboratory workers have at all times used their own bodies as a ready method

of giving them the materials or data they required as standards. The Dutch microscopist Leeuwenhoek, who was the first to see bacteria, obtained them from material he scraped off his own teeth.

In certain researches small quantities of blood are required from time to time in order to afford a standard of normal color in matching specimens of patients' anemic blood. Those doing this kind of work invariably prick their fingers or ear-lobes for this purpose. Professor J. B. S. Haldane, F.R.S., of Oxford and Birmingham, in the course of researches of this nature, has administered to himself on countless occasions the very poisonous gas, carbon monoxide.

Quite often, too, in the laboratory, supplies of air from the lungs are needed in connection with certain kinds of gas analysis; these are invariably collected by the workers from their own lungs. Here again Professor Haldane has been the leader of a band of workers fired by his enthusiasm. Their work on mine rescue-apparatus has proved to be of the highest value.

The effect of very low barometric pressure is an important subject at the present time, especially for aviators. Very low oxygen pressure is their special trouble.

In order to study the effects on the body of the great diminution of the pressure of oxygen, Professor Barcroft, of Cambridge, and a band of coworkers have lived on the summit of the peak of Teneriffe and on Pike's Peak in Colorado. Here they made observations upon themselves and gained knowledge which has already proved most valuable to aviators and to those exploring very lofty mountains, as for instance Mount Everest.

In order to settle a disputed point about the condition of the blood when one lives in an atmosphere where the pressure (tension) of oxygen is very small, Professor Barcroft volunteered to be shut up in a glass case in which the oxygen pressure had been greatly reduced. At the end of eighteen hours a specimen of his blood was analyzed, and its state corresponded with what he thought it would be from purely theoretical considerations.

To study mountain sickness as thoroughly as possible a physiological observatory was built on Monte Rosa; and here many biologists, by experimenting on themselves, have gained an insight into that distressing result of life at high levels.

A great deal of the physiology of the pulse and heart has been worked out by the physiologists' experiments on themselves. Some years ago a young professor at a Canadian university was found dead in the laboratory with an instrument for recording the movements of the heart still strapped to his chest.

One of the latest triumphs of experimental skill in medical research is the exceedingly delicate instrument, the electrocardiograph, which records photographically the electric currents of the beating heart. This work which led to the diagnosis of unsuspected forms of heart disease has been done almost entirely on the hearts of the physicians themselves.

Students, especially medical students, have at all times willingly allowed themselves to be experimented on by their teachers.

In a rather notable series of observations carried out at the London Hospital by Professor Leonard Hill, F.R.S., eight student volunteers were shut up inside a specially constructed cabinet with a glass side so that the effects of the stagnant, hot atmosphere might be studied. When the oxygen had fallen to about 10 per cent. and the carbon dioxide risen to 4 per cent. and the wet bulb thermometer read 85° F., they began to suffer extreme discomfort. To their astonishment they could not light their cigarettes. Without providing any better

ventilation, the electric fans in the roof were started with the result that the discomfort was very rapidly diminished. The air set in motion had cooled the skin and allowed a refreshing escape of heat therefrom.

Two very interesting control experiments were made on volunteers thus—a student outside the cabinet breathed through a tube air that had come from inside it: he felt no discomfort whatever, because his skin was cool; but, conversely, when one of those inside the cabinet breathed fresh pure air from outside, his uncomfortable sensations were not in any way relieved. All these experiments showed that the discomfort arose not from any chemical state of the air in the cabinet but from its moist heat—a physical condition.

A great deal of our knowledge of digestion has been ascertained through experiments on the human being. The very assiduous and fertile worker in Italy, Lazzaro Spallanzani, at the end of the eighteenth century made many observations on himself in order to ascertain the influence of the gastric and other juices on various kinds of food.

He swallowed bread sewn up in linen bags which after their passage through the body showed that the bread had disappeared—it had therefore been digested and absorbed. He then passed on to experiments which involved the swallowing of meat, bone, tendon and cartilage in small wooden tubes with a number of small holes in them so that the digestive juices could gain access to their contents. On being passed from the body, the condition of the material inside the tubes afforded valuable information about the nature of digestion—a subject concerning which in Spallanzani's day there was very little accurate knowledge. These experiments on himself corroborated those on digestion in the lower animals.

In order to make observations on the acidity of the human gastric juice, Spallanzani did not hesitate to regurgitate from the stomach what it might contain after a longer or shorter time from the last meal.

The American doctor, John R. Young, when preparing data for his graduation thesis at the University of Pennsylvania, made experiments on himself (1800–1803) of the same kind. The title of his thesis is: "An experimental inquiry into the principles of nutrition and the digestive process." He corroborated Spallanzani by showing that normal gastric juice is acid, but he thought the acid was phosphoric, whereas we now know it to be hydrochloric; a fact proved a little later by an Englishman, Dr. Prout.

Apropos of the act of deglutition, two German professors about thirty-five years ago devised a long, tube-like, india-rubber recording instrument which one of them swallowed so as to give a graphic record of what the muscles of the gullet were doing during the process of swallowing first solids and then liquids. They found the exact mechanism was not the same in both cases.

As may readily be supposed, when the object of the investigation was the effect of different kinds of foods upon the human constitution, the investigators had no hesitation in eating all sorts of things in varying quantities.

Again, medical students and laboratory servants volunteered to be experimented upon when Professor Chittenden, of Yale, who was studying the effects on human beings of taking much smaller quantities of meat foods than is usual (what is technically called the minimum protein intake) induced a number of students to submit to live on diminishing amounts of this kind of food until the quantity was only one third of that usually taken.

One remembers the fasting men of the nineties, the professional Succi, the Italian, and the amateur, Dr. Tanner, M.P., the Irishman. Each fasted for at least forty days. Dr. Tanner is alleged to have had no solid food but only water

during his ordeal; the professional had an "elixir" of secret composition to sustain him. Succi allowed a committee of physiologists to investigate his case, and some important facts in biochemistry were thereby obtained.

One Dutch physiologist has subsisted for some days on nothing but oil and wine in order that he might study the diseased state acidosis which is induced by that kind of diet: a good deal of light, very much needed at the time, was thrown on that condition, which may also occur as the result of underfeeding and other causes.

Allied to researches on food are those which involve muscular work being done so that the effects of food or some other variable on the output of energy may be studied. Physiologists have devised several forms of work-measurer (ergometer) one of which is a bicycle-like machine on which the experimenter sits and does (external) work, the amount of which is registered on a dial.

But long before the days of geared bicycles, two foreign physiological chemists, Fick and Wislicenus, desiring to study the effect of diet on bodily work, climbed one of the Alpine peaks—the Faulhorn—in order to accomplish a measurable output of energy on a known amount of certain foods.

The work done was that of raising their bodies through the height of the mountain; in fact they "gat them up into the high mountain" to ascertain the relations of food to bodily work under definite conditions.

The most spectacular case of men experimenting on themselves in this line of work is that of two American physiologists, Atwater and Benedict, who constructed what is called a respiration-cabinet, a small heat-proof room in which they could do measurable work on the bicycle and where all their heat was absorbed and measured. In this way, they ascertained very accurately what became of the potential energy of their food.

Those who study the action of all kinds of new drugs—the pharmacologists—have never hesitated to test on their own persons the action of the many substances which they have to investigate. One of the earliest examples of this sort of thing was the foreign physiologist Purkinje, famous in biology for having coined the word "protoplasm." On himself he tried the action of all the following—belladonna, camphor, opium, stramonium and turpentine; and he died in his bed!

But medical men have not hesitated to give themselves certain diseases in order that some disputed points about these might be cleared up.

One of the greatest English naturalists and surgeons, John Hunter, deliberately inoculated himself with the poison of venereal disease. Hunter wished to clear up the confusion which existed in his day regarding syphilis and gonorrhea. His self-inoculation proved only too successful from a purely scientific point of view, for in due time he developed the hard chancre of true spyhilis, ever since called "Hunterian."

There is now no doubt that a great deal of Hunter's subsequent ill-health and fatal illness must be directly traced to his voluntary martyrdom in the interests of exact medical knowledge.

One of the best known cases is that of the son of the late Sir Patrick Manson, who allowed himself to be inoculated with malaria in London and proved that climate as such has nothing to do with that disease, but that it is communicated solely by infected mosquitoes. Young Manson was bitten by some malaria-carrying mosquitoes; and in due time developed typical malaria in England. By appropriate treatment he recovered from this disease only to die a few years later by being accidentally shot.

As long ago as 1842, when the cause of the serious skin disease Favus or "ringworm" was not precisely known, a German doctor, Robert Remak, inoculated himself with a fungus which he

suspected of being the one to blame. He developed typical ringworm and so settled the point in doubt: he named the fungus after the specialist on skin diseases, Schönlein, with whom he had been studying in Berlin (Achorion Schönleinii).

Much nearer our own day, in 1883, Pasteur, who had just discovered the now celebrated cure for hydrophobia or rabies, was quite prepared to inoculate himself with that frightful disease and subsequently inject himself with the curative attenuated virus. Luckily, just as Pasteur was about to do this, the chance of snatching from death, as he phrased it, a little Alsatian boy bitten by a mad dog some days before presented itself, and so relieved him from this operation on himself. Thus Joseph Meister was inoculated and lived.

A most distinguished neurologist, happily still living, cut in his own arm one of the nerves of his hand in order to study the exact order of the return of the different kinds of sensation with which the hand is endowed. The information required, involving as it did observation by an educated mind, was very difficult to gather from hospital patients, and so Dr. ——— cut his own ulnar nerve at the elbow and observed the phenomena for himself. Full restoration of all the sensations was not brought about for one year.

As one might suppose, the effects of anesthetics were nearly all tried by the experimenter on himself before being made public. Thus Humphry Davy, in 1880, inhaled nitrous oxide or "laughing gas" on many occasions before he ventured to announce the new anesthetic. When he did, he suggested its use in exactly the kind of case in which it has proved so useful—"surgical operations in which no great effusion of blood takes place," namely, in dentistry.

The experiments of Sir James Simpson with chloroform on himself, his assistants and relatives are perhaps the most celebrated of auto-experimentation in the history of medicine. Miss Simpson, in her vivid and interesting life of her father, says that he always tried a new drug on himself first; and that on one occasion he was insensible for two hours from the results of taking some compound of more or less unknown composition.

Simpson tried a great many anesthetics before chloroform was finally adopted.

Dr. George Keith and Dr. Matthews Duncan were faithful henchmen in sharing with their master all the risks of the unfamiliar properties of chloroform.

It was in the winter of 1847 that Simpson, Keith and Duncan would sometimes be all under the table at one time; and there was no page-boy to loosen their cravats.

We are told: "These experiments were performed after the long day's toil was over at late night or early morn." Sir James's niece, Miss Petrie—the first woman to be put under the influence of chloroform—was boldly experimented on in the interests of the cause.

Clark, the butler, too, not only experimented on himself but on one occasion gave chloroform to the cook. His method of administering it was evidently calculated to insure its popularity, for he mixed it in such "a richt guid willie-waught" of champagne that that good lady was prostrated in a few seconds on the kitchen floor. He had to call in "his master's voice" to restore the most important member of the household to the consciousness of the light of common day.

The butler took a great interest in the chloroform investigations; he watched his master trying new and unfamiliar substances; but as time went on his belief in the superiority of chloroform increased, and on one occasion he adjured Professor Simpson with solicitude and familiarity:

"Stick to the Chlory, Sir James, stick to the chlory!"

THE MACHINE AND MANAGEMENT

By Professor FRANK T. CARLTON
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No competent engineer would build a bridge or design a locomotive without careful and painstaking consideration of stresses and strains, of the forces of gravitation, of adhesion and cohesion, of factors of safety and of a multitude of other fundamental factors. To do otherwise would be to invite disaster. Likewise, if it runs counter to fundamental social forces, no plan for evolving a better social and industrial edifice has a reasonable chance for success. Experiments in industrial management and personnel administration constitute investigations into the complexities and perplexities of social science or of human engineering. Obviously, the determination of a rational labor policy involves the consideration of complicated and delicate forces. Nevertheless, nearly every person feels entirely competent to determine offhand labor policies, political programs and social platforms with only the aid of preconceived notions and inherited beliefs. Many are the blind attempts which are being made to solve industrial problems. In most cases, the experiments remind one of the man ignorant of the automobile who tries to eliminate engine trouble by acting along the lines suggested by a series of haphazard guesses as to the difficulty; but ignorant social experimentation is often costly. As a rule when attempts are made to analyze the fundamental causes of industrial strife, the assumption is made that the conflict is clearly one in which employers and investors are lined up in antagonism to the employees and wage receivers. The elements of friction are assumed without further consideration to be due primarily to differences in interests and points of view of employers and employees. The socialists and the conservatives have accepted these *a priori* premises. If this view be accurate, the solution evidently must be found in attempting to discover common interests in industrial peace and in minimizing points of disagreement; but it may be necessary to delve more deeply into the intricacies of human psychology and of racial inheritance.

Recently these other aspects of the problem have begun to win a hearing. Bernard Shaw insists that civilization is too complex for the intellect of short-lived human beings to comprehend and intelligently to direct and control. Civilization is likely to be ground to pieces by forces of its own generation. Lothrop Stoddard has painted a picture of the menacing group of undermen. Thorstein Veblen has philosophized about the effect upon man of the machine process. Arthur Pound has attracted much attention by his interesting analysis of the Iron Man and its influence upon Flesh-and-Blood men. Mrs. Bruere has focussed the attention upon the urge to spring planting which the uncontrolled machine process insists must be inhibited. And Professor J. M. Clark has outlined the "Empire of the Machine"—a realm in which human beings have accepted the rank of servants or the status of a subordinate class. The new industrial fabric is considered to be a web entangling the human race. The latter writer suggests "that the unrest

of labor is not a fight for wages and hours merely, but more fundamentally a revolt against the bald fact of servitude, and that it is at bottom servitude to the machine rather than to man." Consequently it can not be cured by high wages, improved working environment, shop committees or personnel management—helpful as these may be. From this point of view, the industrial struggle is either one connected with the growing pains of a society which is being depersonalized and becoming machine-dominated, or it is the death struggle of the old society of primitive, ancient and medieval craftsmen who knew not the machine.

If the friction in industry to-day may be attributed in no small degree to the difficulties of adapting man—an extraordinary complex of instinctive impulses—to the regularity, routine and monotony of the work of a machine tender or helper, if it be a conflict due to the pressure of machine industry and, therefore, to the necessity of adapting a roving and restless people to the requirements of routine and repetitive industry, a quite different task confronts human society. If the second concept be fairly accurate, the industrial conflict is in part a struggle of human beings against a machine or technological system which they have built up step by step and which now ominously threatens to bring down upon their heads the edifice which is called civilization. Must man be adapted to the machine, or is it feasible to make the machine process the servant of civilized society? The second aspect of the problem is now to be placed under consideration.

The primitive man knew little or nothing of punctuality and routine. He hunted and fought at irregular intervals. He took little heed of the morrow; work was not on his short list of virtues. The primitive, ancient or medieval man was little bothered by clocks, cost accounting, efficiency, conservation or machines of any sort. Uncertainty, the alternation of famine and plenty, leisure to-day and strenuous exertion to-morrow, ennui of idleness to-day and to-morrow the climax of a thrilling hunt were typical of the long ages of the primitive world in which the great fundamental characteristics of human nature were molded. The primitive man constantly faced the world of nature. On the other hand, relative certainty, the doing of the same things to-day and to-morrow that were done on many yesterdays, a humdrum level of a reasonable standard of living, unless the job is lost, is to-day's portion. The great uncertainties of to-day in the normal times of peace are the prosaic and unheroic ones of unemployment and sickness. The environment of the typical city and shop worker is man-made—paved streets, rented houses, municipal water and lighting, commercialized amusements, the artificial thrill of the melodrama on stage and movie screen. The discipline of the machine age runs counter to deep-seated impulses, social habits and mores. Unrest seems inevitable. The worship of regular work, of work for work's sake, is a product of an age of machinery and efficiency; it is a new cult. Irregularity and immorality are being tied together. The ultra-modern concept that business is the end and aim of industrial activity is machine-made. From the point of view of human beings, business for the sake of business is a futile slogan. Business should be carried on for the sake of better and happier men, women and children, not for more and more machines and investments.

Within a comparatively short space of time, the machine has gradually assumed a dominant position in the world. If to-day the machine process ceases to function, man is helpless. Man's dependency

in the centuries preceding the nineteenth was upon natural forces—climate, moisture, wind, flood, drought, change of seasons and the like. Gradually, but inexorably, the machine and its friend fellow-worker, science, have conquered the forces of nature. Only occasionally when these forces get temporarily out of grasp of the machine and of science do the old familiar foes of mankind become menacing.

But, as imperceptibly and as inevitably, mankind has passed under the velvet-covered yoke of the bounty-giving clan of the machine. We live where the necessities of the machine dictate—smoky and dingy Pittsburgh, the repulsive oil fields of Wyoming, the desolate sand prairies of Gary, the tenements of the East Side of New York City. The vast immigration of recent decades is in direct response to the call of the machine. We get up in the morning, continue at work and return home in accord with the will and pleasure of the amalgamated association of machines. Man is becoming —yea, is—the valet of the machine. The leading economists and students of business affairs are studying business cycles in order to appease the wrath of the "God of continuous utilization."

By inheritance, mankind is fitted for irregular and seasonal work. Men were hunters, fishermen, shepherds and agriculturists long before the industrial age appeared above the horizon. Not until the nineteenth century was any considerable group of men pried loose from the soil and tied to jobs in shops and office. Not until after the dawn of the nineteenth century were persistent performance and routine exalted to the ranks of major virtues among the great masses of mankind. The machine process is responsible for the respect shown the dictum "that wanderlust and productivity have become mutually exclusive." Business experts, engineers, bankers and economists bowing to the dictates of the machine process are much concerned with the reduction of seasonal and cyclical variations in business. On the other hand, the biological and psychological inheritance of mankind points toward the desirability of seasonal fluctuations and variety in industry.

If, from the engineer's point of view, workers are to be adjusted to the requirements of a highly organized and efficient industrial order, regularity and routine must become second nature. The wanderlust, "the call to spring planting," the frequent trips to forest and stream must be inhibited. Jungle and unutilized river banks must give way to the stern demand for complete utilization, and the ideal man of the new order will become a sort of animated machine. The increasing prevalence of the vacation is a gracious concession on the part of the clan of machines to the biological background of capricious and untamed men. If, on the other hand, industry be required to yield precedence to men, seasonal fluctuations in industry will remain, industries will be dovetailed, and regular industry will be encouraged to become irregular so as to cooperate with seasonal industries. More emphasis will be placed upon the development of normal human beings.

Is there hope for man? Can it reasonably be anticipated that he will dominate the machine? Or must he be content to continue subordinate to the great machine clan? Is the new art and science of personnel management to aid man to dominate the machine, or will it merely point the way toward a more rapid and peaceful acceptance of man as the machine tender? For years, the conscious and unconscious program has been that of adapting man to the requirements of machinery and technological processes. Only, after we have met serious obstacles, after civilization is in

danger of being broken between the discordant requirements of machines and the inherited tendencies of human beings, and after machinery has obtained an almost impregnable footing, has the race of men started upon the study of social forces, of human interrelationships, and of the relation of men to machines. Can machinery and science become tools to produce commodities and services for men instead of for the further advancement of the machine age and the subordination of men to the requirements of the machine?

If man is to be domesticated to the machine, what type of man will result? If the Iron Man is to win in the struggle with the Flesh-and-Blood Man, will the fittest to survive be the docile and sluggish machine tender, the mechanical engineer, the business man of the Babbitt type? Are the men of initiative who rebel against monotonous work and red-tape, who refuse to worship with the aggressive group of efficiency experts and home town boosters, to be pushed to the wall as machine industry moves forward triumphantly to conquer new fields? The famous humanitarian group in pre-Civil War New England went out in a blaze of intellectual fireworks before the onward tread of the youthful factory age. Is this a portent of what is to happen wherever the machine extends its sway? Is the human intellect to become "machinized"? If so, if the machine be the victor, if the requirements of the machine process are to determine the characteristics of the working group, then the problems of the industrial world are those of adapting mankind possessed of certain inherited characteristics to this new machine-dominated world. However, this seems to run counter to the implications of democracy. Universal education and the free school system are supposed to place emphasis upon traits which are very different from the docility required of machine tenders. A good citizen in a democracy is not a docile, unthinking, machine-like creature.

Business as it is carried on to-day is favorable to machines rather than to men. Business is carried on in order to get more business. Savings are poured into industry in order that more machines and capital may be produced. Capital begets Capital. The great Ford business has had a high birth-rate. Capital valued at approximately one hundred thousand dollars has multiplied with little or no immigration or influx of dollars from outside investors until it is numbered by the hundred millions. This has taken place within a score of years. The annals of human birth-rates exhibit no parallels. And, in this enormous and youthful machine plant or organism, mere human workers must obey without questioning the dictates of the engineers and business experts who act as the interpreters or high priests of business efficiency. Indeed, what is business efficiency to-day except conformity to the dictates of the amalgamated order of machines? The "fool-proof" machine—with the orderly processes of which the human being can only with difficulty interfere—is the high-water mark of machine technic.

The corporation is the acme of impersonality. Up to date the large corporation constitutes the finest token of machine domination and of human subordination. It is the crest of the wave which is submerging the old order of men and which is making us slaves of the machine process. Men may come and men may go as managers, owners or wage-workers without in the least affecting the even tenor of the progress of the corporation. The modern trust company in its advertising boasts of its superiority over the human or natural person.

The preeminence of the machine is making the old life of semi-isolation with its emphasis upon individual and family

traits chiefly a matter of historical significance. Street life, factory life with its groups of workers engaged in common tasks, the educational system with its large classes and units, common and standardized amusements, the growth of club and fraternity life—all tend to mark the members of industrial society with a similar stamp. Even the family, that stronghold of individualism, is seeing its influence upon child life gradually weakened. Medical clinics, hospitals, kindergartens, supervised public playgrounds, the public schools, the popular amusement house, the automobile and the radio are all reaching out for functions which were the monopoly of the old-fashioned home of the isolated pioneer. And, furthermore, the working-away-from-home mother and the working-away-from-home children were unknown in the case of the traditional American home.

Even in the educational world the struggle is on more or less consciously between those who advocate that the youth should be educated so as to make for initiative and thoughtful resourcefulness and those who would mold the youth to fit into the modern machine process and business technology as carefully drilled specialists who may readily become excellent valets of the corporation and the machine. In the world of machines, standardization is a word and process which is given high rank. Our school system has succumbed to the pressure of machine requirements. Pupils are being standardized and regimented in an unprecedented manner. The ideals of education are becoming deeply colored by the machine process. To turn the machine into a servant of man may be only the hope of a Utopian. Perhaps science can only be the friend and coworker of the machine. Nevertheless, if there be such a science as social, its function is to enable man to regain premiership in the realm of industrial institutions.

Fortunately, there is plausibility in the assertion that the evils of the machine process are due in a large measure to the incomplete expansion of the sphere of the machine, that industrial friction to-day is in a large measure a growing pain which will pass away with more complete utilization of the machine. If the present considerable restriction of immigration into the United States is continued for a few years, a notable laboratory experiment in social science may be worked out. Scarcity of workers and high wages furnish an incentive to the wide-awake enterpriser to utilize more and more machinery. While the industrial progress of the United States has been hastened and its direction modified by the great influx of immigration during the last decades of the nineteenth century and the opening years of the twentieth, restriction of immigration will doubtless hasten further use of automatic machinery. The Iron Man may take the place of the semi-automatic worker. The fear that machinery necessarily calls for morons and other low-grade workers may prove to be unfounded. Adequate development of machinery may lead to the displacement of morons and the lower grades of unskilled workers by automatic machinery with skilful operatives and repairmen. The "empire of the machine" may prove to be in actuality the empire of the skilled worker, the trained technician and the cultured human being.

The application of scientific methods will elevate many a task from the status of distasteful drudgery to that of a skilful and attractive job. This tendency is thrown into clear relief when a contrast is drawn between the operator of a steam shovel and the wielder of the old hand shovel, between the washing of dirty clothes by bending over the washboard and by means of the electric washer, or when a comparison is made of the engineer of a central heating plant and the

fireman in a small flat. Harness a job to machinery, natural forces and scientific knowledge, and the ugliness is often sloughed off. Indeed, a new dignity attaches to such work. A large supply of unskilled workers helps to tie the workers to the machine; the latter sets the pace. Limit the supply of unskilled workers and the machine is requisitioned to do new tasks. The machine then becomes the tool of the worker.

Scarcity often gives distinction; it is an element in value. It is not unreasonable to argue that with increasing scarcity of workers willing and eager to perform menial and unlovely tasks, may come a higher esteem for those who are willing to perform necessary but disagreeable tasks. In a large city, the collection of garbage is an essential occupation; a scarcity of garbage collectors may lead to the ascription of more merit and the payment of higher wages to those who perform such tasks.

It is not entirely unreasonable to assume that civilization is only on the threshold of the age of machinery. The machine is introduced very slowly in countries where wages are low. Better training on one hand for the coming generation and a decrease in the number of poorly trained or unskilled may lead in the next few decades to an unprecedented increase in capital and in output, and also in dependence upon scientific methods. Machinery may become in truth the servant of an educated mankind. May it not be that the evils in our factories and workshops which are attributed to machinery are in reality the result of the partial use of machinery? Are not a great multitude of routine machine feeders and tenders doing work which the machine can and will perform if machine feeders become scarce and able to obtain high wages? Imperfectly developed machinery makes man the slave of the machine; but a fully developed machine age emancipates man from drudgery and unskilled work.

The skilled worker may become the normal type of American wage earner; and opportunities for high-grade positions may in the future depend less upon a great supply of unskilled workers than upon an adequate supply of capital. The fully developed Iron Man can be made the servant of man; the Iron Man may not necessarily be an evil spirit condemning vast hordes of humans to routine and drudgery. A notable increase in scientific and purposeful education may place mankind on the threshold of new and alluring possibilities of productivity, of social betterment and of industrial peace. The problem of achieving industrial peace, let it be repeated, is one in social mechanics; and it is not Utopian to urge that the solution can be ascertained.

STUDYING THE SUN IN CHILE[1]

By L. B. ALDRICH

ASTROPHYSICAL OBSERVATORY, SMITHSONIAN INSTITUTION

FOR the past twenty-five years the Astrophysical Observatory of the Smithsonian Institution has been engaged in a study of the quality and intensity of the light and heat given off by the sun. Here upon the earth we live at the bottom of a great sea of air. The sun's rays which reach us after passing through the air are very different from those which were actually emitted by the sun. The various constituents of the air—the water vapor, the carbon dioxide, the oxygen, the dust particles and so on—serve to scatter, reflect and absorb the rays in varying amounts and permit only a much altered fraction of the original rays to reach us. Man is not yet able, by balloon, by aeroplane or by any other means, to investigate directly the solar radiation before it has undergone these alterations in the atmosphere. All we can do is to try to measure accurately the rays received here and correct them as best we can for the losses they have suffered.

The problem is an exceedingly complicated one. It has been necessary to evolve special methods and special instruments of great delicacy. The work, first started about the year 1900 under former Secretary Langley, whose name stands so high in the world of aviation, and continued since his death under the able leadership of Dr. C. G. Abbot, showed such promise of valuable results that it has been carried on with increasing vigor all these years. Observations were begun here in Washington, but it was soon evident that reliable work could not be expected in so impure an atmosphere. Expeditions were made from time to time to Mt. Wilson and Mt. Whitney in California, to Hump Mountain in North Carolina, to Bassour, Algeria, and to other places, in order to obtain observations under better sky conditions. Careful investigation was made to find the proper location for a long series of solar observations under the best available atmospheric conditions. Four things were required of the atmosphere: First, that it be as pure as possible, free from dust, smoke and other impurities; second, that it be as dry as possible, because even a small amount of water vapor absorbs great quantities of solar radiation; third, that it be as rare as possible—which condition could be satisfied by choosing a high altitude; fourth, that it be as uniform and unchanging as possible. The place chosen as best meeting these requirements was Mount Montezuma, on the western slope of the Andes Mountains in northern Chile. So far as the institution is aware there is no place in all the world more favorable for its solar observations than this mountain top in Chile. In 1919 a station was established there to make daily observations of the solar light and heat.

In these observations it is important that the instruments be maintained at a constant temperature. To this end they are mounted securely in the interior of a cave dug into the mountainside. A mirror arrangement reflects the sun's beam into the cave where it passes

[1] Broadcasted from Station WRC, Washington, November 19, 1925; one of the Smithsonian series of radio talks arranged by Mr. Austin H. Clark.

through a prism made of special glass. The effect of this prism is to break up the beam into a spectrum showing its component parts. The spectrum thus produced is passed slowly across a very delicate instrument called the bolometer. This instrument is essentially an electrical thermometer so sensitive that it will measure a change of temperature as small as one millionth of one degree. The bolometer measures and records upon a photographic plate the intensity of each wavelength in the whole spectrum, from the ultra-violet through the visible light and including the infra-red or invisible heat rays. Simultaneously with the taking of this bolometer record, the observers are busy with other instruments. One of these instruments measures in calories the total radiation being received at the station. Another measures the brightness of the sky in a definite zone around the sun. These instruments were also designed and built at the Smithsonian Institution. A fourth instrument measures the altitude of the sun, from which we can determine the length of the air path through which the rays came.

Having taken at least five sets of observations at intervals during the morning, the observers must develop, wash and dry the photographic plate which contains the bolometer record. Then with another instrument of special design the plate is carefully measured. After several hours of computing the reduction of the day's observations is completed. So improved are the instruments and methods, however, that one man can take and reduce a complete set of observations in one day, whereas formerly two men would require at least a week to obtain a similar result. The final result of a day's work is a number called the solar constant. It represents in calories the total radiation from the sun which would reach the earth per unit of surface if there were no atmosphere.

Unfortunately for the men who do the observing, the most favorable place for solar study is otherwise most unattractive and desolate. A more dreary monotony both of landscape and climate would be difficult to find.

In January, 1923, it became my duty to take charge of this station and to occupy it for two and one half years. Imagine, if you will, this mountain top, 10,000 feet above sea level, in the heart of the great desert of Atacama. This desert, over whose surface is scattered the peculiar deposit which yields the widely known and valuable nitrates of Chile, is often referred to as the most desolate desert in existence. In this desert are found rich deposits of copper and other metals. It is a curious fact of nature that here where nothing of value is found above ground an unusual abundance is found below the ground. To reach our station one rides all day in a curious narrow gauge train winding its way up to the gradual slope from the port of Antofagasta. All day long as far as one can see on either side there is no sign of life, neither animal nor vegetable. The sun shines with astonishing brightness from a cloudless sky. Occasionally the train stops at a nitrate oficina or shipping point for the crude nitrate gathered from the soil. At nightfall we reach Calama, an old Indian village and probably a southern outpost of the old Inca civilization. Here we disembark and drive our auto out into the desert, winding upward to the top of Montezuma. In this desolation, with no living thing, plant or animal within a radius of twelve miles, the Smithsonian Institution has its solar station. Here on the northern slope the great cave for instruments has been dug and a small shop and house built for the observers. Here, with his small family and one

assistant, the observer lives, Robinson Crusoe-like, in primitive fashion save for such comforts as he can install with his own hands. All supplies including water he must bring by auto from Calama. Here he must work out his own problems, surrounded by a maximum of monotony and desolation. The view on all sides is an unchanging, rolling desert broken only by the grandeur of the high Andes in the background to the east. Over twenty of these snowcapped peaks are visible, one of them a smouldering volcano whose smoke we could occasionally see. The weather is even more monotonous than the view, for each day is a repetition of the previous day. A cloud in the sky is very rare—rain, even of a few drops, is almost unknown. The sun shines with a brightness we never experience here. The air is so dry that one's lips and hands are chronically chapped. Each day is warm, each night is cold, often down below freezing. Each morning is calm, each afternoon there is a strong westerly wind subsiding at sunset.

One would naturally wonder how life could be made bearable in such environment. We found it not only bearable but full of interest. There were even advantages we do not have here. There were no flies, no insects, nor unpleasant creatures of any kind. We were free from the annoyance of disagreeable neighbors and lived our lives as we chose, unhampered by the conventions and obligations of city life. The official work of the observatory of course occupied the larger portion of our time. Our spare time was devoted to improving our living conditions. Many a thrill of pleasure we experienced as we settled down to enjoy some comfort we had made ourselves. One innovation in particular pleased us. We brought down with us an ordinary farm windmill, mounted it at the very top of the mountain and attached an electric generator to it. Thus we harnessed the daily afternoon wind, charging storage batteries which furnished electric light and power sufficient for all the needs of the station. That windmill is still faithfully performing its duty of supplying the comforts of electricity to my successor in Chile. We were fortunate in having also such luxuries as a piano, phonograph and many good books, and since my return a radio has been installed with which it is hoped our observers will be able to listen in on North American programs. Some drawbacks there were in the desert life, more particularly in the lack of variety in food and in the lack of proper medical and dental attention. But taken all in all, we look back upon our desert life as full of interest. Our frequent contacts with the inhabitants of Calama, mostly Bolivian and Chilean Indians, picturesquely dressed in homespun clothes, the women in huge gathered skirts of bright colors (we were authoritatively told their skirts measured ten yards around the bottom), the men wearing sashes and gay-colored ponchos, the droves of llamas bringing down the llareta, a peat-like moss from the high Andes universally used for fuel, the scrupulous politeness of the natives, the curious mixture of quaint Spanish and Indian dialect they spoke—all these things were impressed on our memories.

I must not fail to mention the greatest asset we found there. Mr. and Mrs. Drummond, a typical Scotch couple who have lived for many years in the quaint little village of Calama, took a great and intelligent interest in our work. They did all in their power, in innumerable ways both great and small, to add to the comfort of the observers as well as to further their work—and all without expectation of reward. To find such friends in such a place did more to encourage us than any other factor.

We may well ask, of what value is this study of the sun in such a place? In addition to the purely scientific viewpoint—of adding to our knowledge of solar radiation—there is another factor of importance to us all. The so-called solar constant is shown by our observations to be not a constant but to fluctuate irregularly from day to day through a small range. It is surely reasonable to assume that this daily variation must have some effect, however remote and however complicated the process, upon the weather here upon the earth. The promise which our work holds, namely, of adding a new element to the present means of forecasting weather, is of interest to all. The Weather Service of the Argentine government has for several years used our Montezuma results, which are cabled daily to Buenos Aires, and finds them of value in improving their weather forecasts. In recent months the Montezuma values have also been cabled in code to the Smithsonian Institution. They are being used by Mr. H. H. Clayton, a prominent meteorologist, in a study of the correlation between our solar values and the known weather conditions about New York. This study also has already made encouraging progress.

In so complicated a research, even the best of skies, of instruments and of observers fail to produce perfect results. We are constantly on the alert to improve them. But the biggest aid to better results would be the establishment of a series of stations in widely separated places, under the best sky conditions, all carrying on the same line of observations. To this end, the Smithsonian has a second station at Table Mountain in southern California. And but three weeks ago our director, Dr. Abbot, left on a six months' tour of the eastern hemisphere in search of the best location for a third station. This third station is made possible through the cooperation of the National Geographic Society. With these three stations, one in the desert of northern Chile, one in southern California and one in the best location to be found in Asia or Africa, we hope and confidently believe the Smithsonian Institution will produce results of great value to mankind.

WHY DON'T WE FLY?

By Dr. EDWIN G. DEXTER

FOUR or five years ago it was confidently predicted that by this time aeroplanes would be as common as flivvers; that we should be commuting by the air route and taking our afternoon recreation in clouds other than those of dust. But are we? And if we are not, why not?

Mechanically, aeronautics have advanced according to prediction. The continent has been spanned with the sun. Our triad of planes has rounded the globe in its triumphal march. Our mail is going from coast to coast on a thirty-hour service. Commercial air routes are in successful operation all over Europe and in some portions of our own country with a hazard to life and limb not much in excess of that of terrestrial travel. But after all, the thing has not taken hold. Why is it?

I have yet to see discussed in print what seems to me to be the real cause. The mechanical difficulties can be surmounted, those of the plane itself, those of landing fields—they are easy. But how about making over in a single generation, or even in many generations, a terrestrial animal into a celestial being?

Since the commencement of organic evolution, we and our ancestors, nobody knows how many generations of them, have lived on solid earth and we feel safe and at ease there and nowhere else. We are accustomed to travel there. It is true that from the ox-cart to the automobile the rapidity of terrestrial travel has been increased many fold, but the change is after all quantitative and not qualitative. Even though the first time we made fifty miles an hour in an automobile we were a little worried, time cures that and it is not long before we accept it with equanimity, because we are just as near terra firma as we were in our buggy days. But it is very different a few thousand feet up. I know, because I have tried it.

For some months I was in such relation to a government department as to have air service at my disposal whenever needed for official duties. I was up a dozen times at least, and perhaps twice that number. I didn't keep track. I pretended that I enjoyed every minute in the air, but I didn't. I kept on to see if I wouldn't enjoy it after a while, but I didn't; and when my wife, who had by the way never made any objection to my flying, asked me if I didn't think my obligations to the family would justify me in accepting a little slower and safer method of transportation, I was glad of the excuse to stop flying. I have never been up since, and I am never going up again unless it be in line of duty.

Don't gather from what I have said that I was ever frightened while in the air. I was not. But I never experienced the restful feeling there that I enjoy. The real difficulty with me, however, and what I feel is going to be the difficulty with the air commuter if he ever comes, is not while in the air, but while out of the air. I think I never decided that I would make a flight the next day and enjoyed the rest of the evening. I never tried a thermometer or a blood pressure machine at such times, but I believe if I had every record would have been abnormal.

I remember twenty-five years or more

ago when living on the western plains that I had two ponies, one of which I always rode when I tried, while the other I sometimes did. The latter was named Rattlesnake. I tried to ride them alternate days. I enjoyed every second of the time after I got one foot into Rattlesnake's stirrup, whether I stayed on or not, and the seconds went fast. On alternate evenings I had nothing on my mind. Those were the evenings after I had ridden Rattlesnake. After a while the thing got on my nerves, and Rattlesnake got lost. I tried every possible way to find him (which I was sure would not succeed) and let all my friends believe that I was heartbroken at losing him.

And mark my word, the first commuter by the air route, yes, and the second and the third, and nine out of ten if there ever be that many, will let his aeroplane get lost or out of running condition within three months. He will probably seem to be just as sorry about it as I seemed to be at the loss of my pony, while in reality he will be just as sorry as I was and no more. But he will travel the land route again just the same. You can't make a man feel at home as a bird.

I do not mean that aeroplanes have no place with non-professional flyers. Probably four people out of five can get up courage enough to make a flight. They will lord it over the rest who have not, congratulate themselves on their courage, tell their friends that they liked it, and make up their minds down deep in their hearts that they will never go again. The other one is obsessed with the "fear of the abyss" and you couldn't hire him to go up under any circumstances. I have personally known a good many aviators, but have yet to find one who is not looking forward to the time when he can give up flying. There probably are some who do not feel that way, but I have failed to meet them. Where are the pioneer flyers whose obituaries you have not read? They are on solid earth, most of them, and you couldn't pry them off.

And the worst of it is—if my thesis be correct that the insurmountable obstacle to popular flying is psychological—that there is no solution to the difficulty. The hazard of flying, though comparatively slight, is sufficiently great to blot out the flying strain. Doubtless the aviator who sticks to it for any length of time possesses an inherent tendency which if perpetuated would develop a breed of flyers. But he is the very man that aviation annihilates sooner or later, without perpetuating the tendency. Doubtless, too, sexual selection enters in. It seems probable to me that the girl who felt it would be just as easy to fall in love with a broker of her acquaintance as with a lieutenant of the air service, would, for prudential reasons, give the broker the inside track, though this might not be true for the extremely romantic type.

We shall perhaps always find men approximately of the Lieutenant Maughn type to man our air service, and there will be enough of us who haven't yet experienced the "ten foot feeling" which comes from having braved the air at least once, to maintain a fairly prosperous commercial aviation. But don't buy stock in the Aerial Flivver Company. You will lose if you do.

A NEW MECHANICAL PHONOGRAPH

By HENRY C. HARRISON

MEMBER OF THE TECHNICAL STAFF OF THE BELL TELEPHONE LABORATORIES

SOUND is probably the most powerful means of conveying emotion. With all due respect to the printed page, sound is probably the most common means of conveying ideas. Furthermore, sound is one of our most useful sources of information, as witness the automobilist listening to the engine or the doctor listening at the chest of his patient.

To make the fullest use of all these experiences, it is of great advantage to be able to reproduce sounds at will. Up to a generation ago, the only method of recording sound was by means of various alphabets and systems of musical notation, the reproduction depending wholly upon the skill of readers or musicians. A first step towards meeting the need for a better and more direct method of recording and reproducing was made in 1877 by Thomas A. Edison's invention of the phonograph. During the nearly fifty years intervening between this first invention and the present phonograph a great deal of effort was put forth to improve reproduction. This effort for the most part took the form of trying multiplied experiments, results being judged by ear. Even in the hands of very able men this method is quite limited in what it can achieve, especially when used on a complex problem such as the phonograph where there are literally millions of possible combinations of parts.

The method of multiplied experiments was successful in raising the quality of phonographic reproduction to a high level but one which still fell far short of perfection. Telephone research work led to the recognition that a phonograph is a wave transmission system, and that the requirements which each part should meet can be determined mathematically. This has tremendously reduced the amount of experimental work required as it is now only necessary to find practical ways of making individual parts whose requirements are fully known. The use of this method has given us a phonograph of a very much higher level of quality with the prospect of practically perfect reproduction in the future. In making the fullest use of the method it has been necessary to develop apparatus for measuring sound output and apparatus for measuring mechanical impedance.

The new phonograph is an illustration of the use in one field of science of methods and knowledge developed in quite a different field. It represents the application to the phonograph of mathematical methods developed primarily for the design of telephone transmission lines and filters. In the early days the theory of electrical wave transmission was commonly explained in terms of analogous mechanical systems, and now reversing this process, telephone transmission theory has been used to design the mechanical wave transmission system of the phonograph. It may not be evident at first glance that mathematical equations worked out for electrical systems may be applied to mechanical systems with merely a redefinition of the constants. If, however, the equations for analogous electrical and mechanical systems are worked out and compared, they are seen to be identical in form and to differ only in their constants. This rests

FIG. 1. MR. HENRY C. HARRISON, THE AUTHOR OF THIS PAPER AND DIRECTLY RESPONSIBLE FOR THE DEVELOPMENT WORK ON THE PHONOGRAPH, EXPLAINS SPECIAL FEATURES OF THE DIAPHRAGM TO MR. JOSEPH P. MAXFIELD, IN WHOSE DEPARTMENT THE WORK WAS CARRIED ON.

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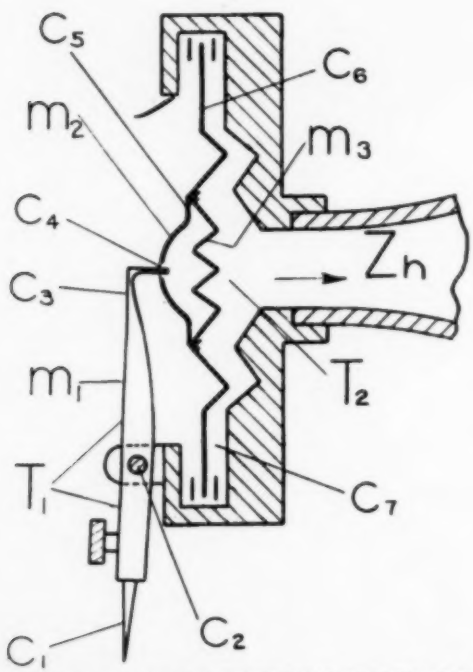

FIG. 2. DIAGRAMMATIC SKETCH OF THE MECHANICAL SYSTEM OF THE PHONOGRAPH.

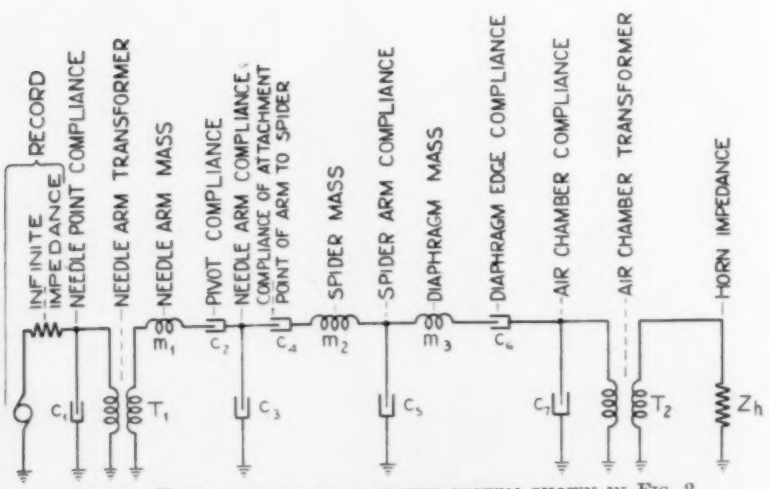

FIG. 3. ELECTRIC EQUIVALENT OF THE SYSTEM SHOWN IN FIG. 2.

on the fact that energy obeys the same laws whether it be in the electrical or mechanical form, and that the characteristic of a system for the transmission of wave energy depends upon three factors: its energy storage elements, its energy dissipation elements and their arrangement. The two common types of storage elements of an electrical system are inductances and capacities, and for mechanical systems the corresponding storage elements are masses and compliances, popularly termed flexibilities. Similarly, the one common type of dissipation element for electrical energy is an electrical resistance and the corresponding feature in the mechanical system is a mechanical resistance. A list of similar correspondence follows:

Mechanical		*Electrical*	
Force = F	(dynes)	Voltage = E	(volts)
Velocity = v	(cm/sec)	Current = i	(amp)
Displacement = s	(cm)	Charge = q	(coulombs)
Impedance = z	(Mechanical ohms or dyne secs/cm)	Impedance = Z	(ohms)
Resistance = r	(dyne secs/cm)	Resistance = R	(ohms)
Reactance = x	(dyne secs/cm)	Reactance = X	(ohms)
Mass = m	(gms)	Inductance = L	(Henries)
Compliance = c	(cm/dyne)	Capacity = C	(Farads)

By using this list of corresponding constants a known electrical equation may be readily converted to an analogous mechanical equation.

The new phonograph exclusive of the horn is as a wave transmission system closely analogous to a low pass filter type of electrical system.[2] Figure 2 gives a diagrammatic picture of the physical parts and Figure 3 gives the electric equivalent showing how the parts are related as a wave transmission system. It will be seen that the record acts as an approximately infinite impedance generator and the needle point as a shunt compliance. The needle arm acts as a transformer and also as a series mass and the needle arm tip as a compliance which is in shunt. The spider acts as a series mass and its arms as a shunt compliance. The diaphragm acts as a series mass and its edge as a series compliance. The air chamber acts as a shunt compliance and also as a transformer and the horn acts as a terminating impedance which above its low frequency cut-off is a resistance. The wave energy generated by the groove travels through the needle arm to the spider, to the diaphragm, to the horn and out to the air. In traveling from one end of the needle arm to the other it is decreased in force, that is, the arm acts as a step-down transformer. At the diaphragm the wave energy changes from its form as the vibration of masses and springs to vibrations of the air or sound. In going from the diaphragm to the horn the total pressure of the sound waves is decreased, that is, this is a step-down transformer. Thus it is seen that the wave energy in its travel from the needle point to the mouth of the horn passes through a complex series of variations and transformations and all of these must be accomplished without loss or distortion and that for the whole range of voice and music frequencies. Mathematical studies of telephone lines and filters have shown that a transmission system such as the phonograph will transmit the whole voice and music range of frequencies without distortion if three conditions are met. First, the parts of the system should be arranged to form repeated filter sections; second, the magnitude of these quantities should

[2] A complete explanation of the matter may be found in a paper presented at the Mid-Winter Convention of the A. I. E. E., February 12, 1926.

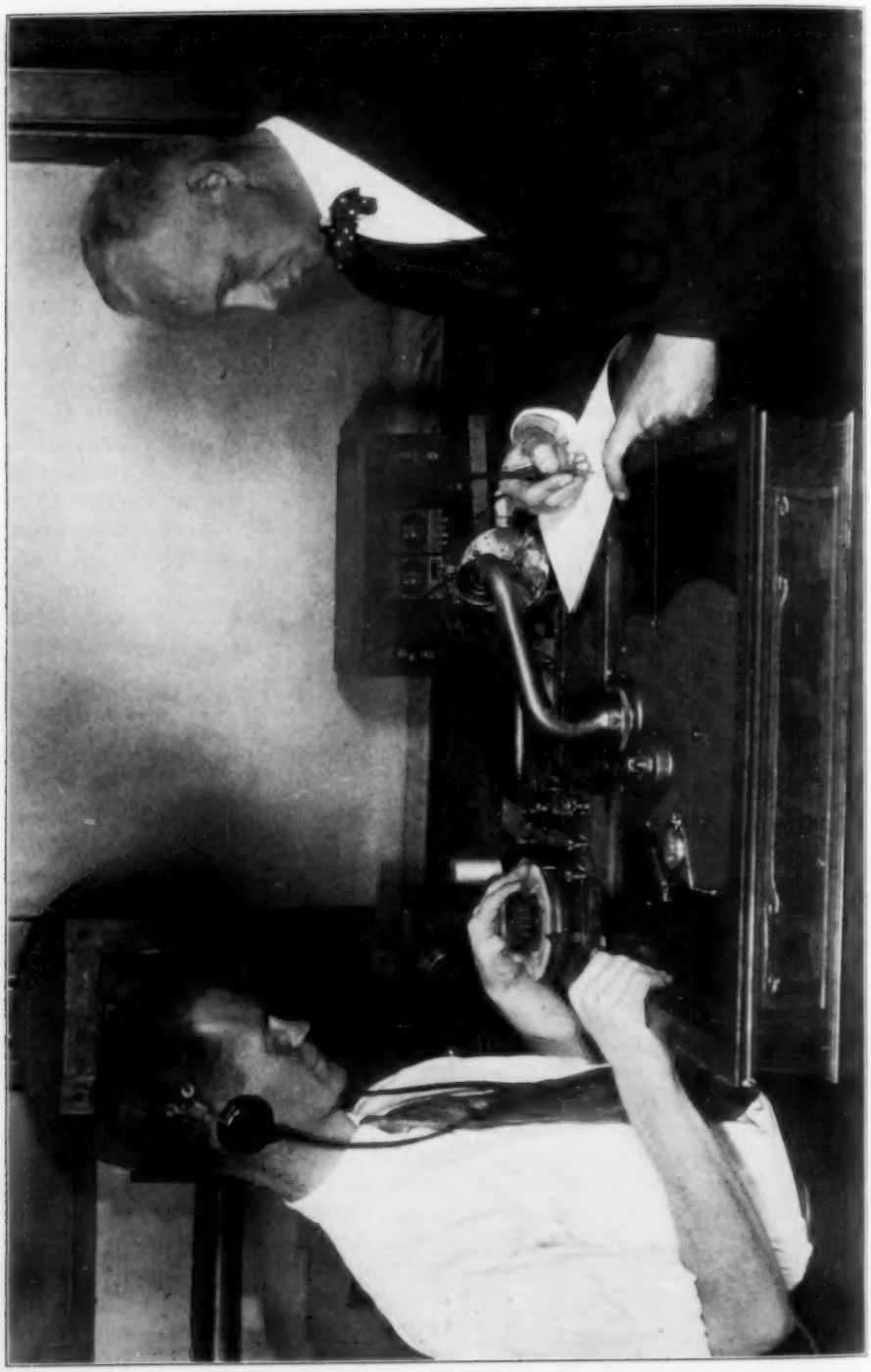

FIG. 4. MR. ALBERT L. THURAS (RIGHT) AND MR. THEODORE OSMER (LEFT) MAKE MEASUREMENTS ON THE PHONOGRAPH WITH A MECHANICAL IMPEDANCE BRIDGE.

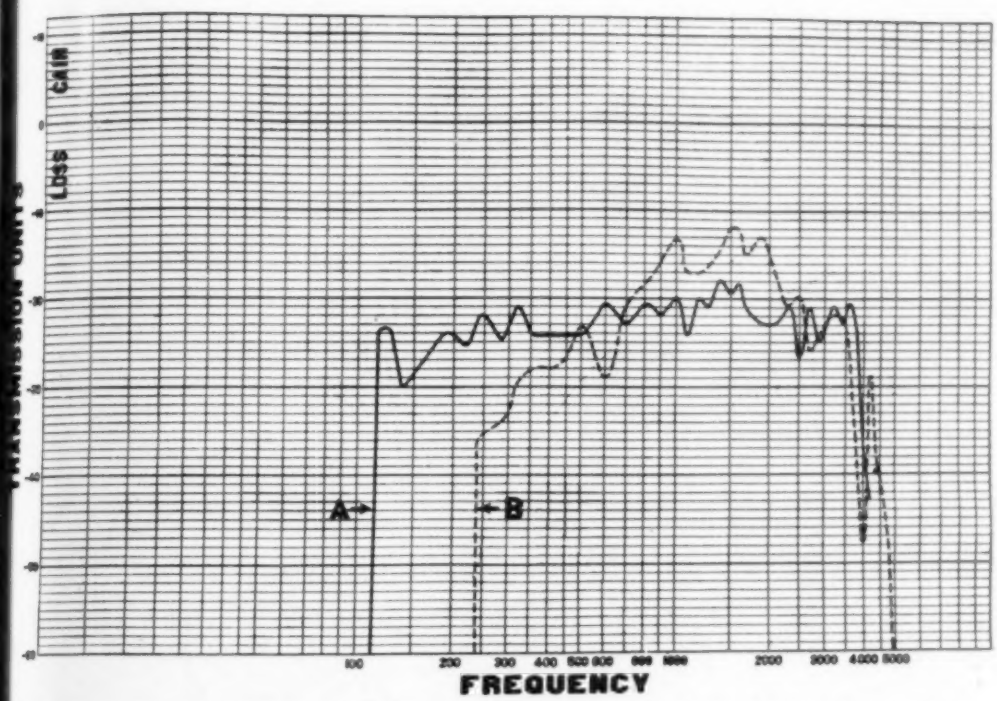

FIG. 5. RESPONSE FREQUENCY CHARACTERISTIC OF TWO PHONOGRAPHS. CURVE A SHOWS THE CHARACTERISTIC OF THE BAND PASS FILTER TYPE DESCRIBED. CURVE B SHOWS THE CHARACTERISTIC OF ONE OF THE BEST PREVIOUS MACHINES.

be such that without transformers the separate sections all have the same cut-off frequencies and characteristic impedances and third, a proper resistance termination should be provided. These conditions were not met by older phonographs, in fact, it is very improbable that they ever could have been discovered or met by the experimental method alone. It was the failure to meet these conditions in the older phonographs that was responsible for their imperfect quality.

For the perfect reproduction of speech and music it is necessary to reproduce the range of frequencies from below 30 to about 10,000 cycles, but a high degree of naturalness is achieved with a range of only 100 cycles to 5,000 cycles. This is approximately the range of the new phonograph but it is anticipated that further development work will extend this somewhat. In figure 5 curves are given showing the range of reproduction both of the new phonograph and of one of the best of the older commercial types. The new type satisfactorily reproduces a little more than 5 octaves whereas the old satisfactorily reproduced only about 2 octaves. In contrast to what is heard on the older phonograph, a person listening to the new phonograph hears the low frequencies as well as the high. Its reproduction of the low frequencies gives naturalness to speech and music, makes it comfortable and carries over the full power of the rhythm. Its high frequencies give clarity and detail. They move the artist's voice from a position down in the throat of the horn right out into the room. They make all the instruments in an orchestra stand out individually, each with its own individual quality of tone.

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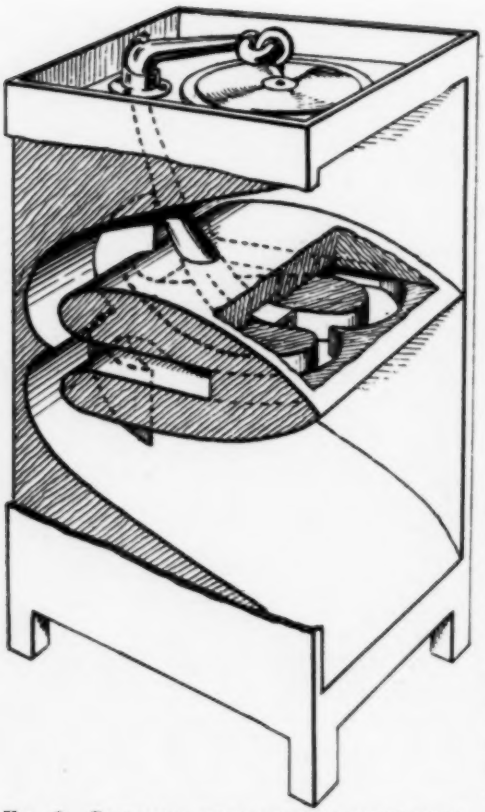


FIG. 6. SECTIONAL VIEW OF THE FOLDED HORN SHOWING THE AIR PASSAGE.

On the new phonograph, not only is a satisfactory range of frequencies reproduced but it is reproduced without partiality, that is, without regions of exaggerated loudness or weakness. We are all familiar with such examples of partiality as the resonance of an empty room or the sound that one hears when one speaks with his head in a rain barrel. These changes in quality are, technically speaking, changes in the distribution of sound intensity with frequency. All speech and music are made up of simple sine frequencies, that is, simple flute-like tones of various pitches and various intensities, the various vowels being distinguished not by the fundamental but solely by the distribution of intensity among the overtones. Because elements of speech have this character, one may speak into a resonator such as a barrel of just the right size and find that although he speaks one vowel a different one is heard. A phonograph with the same peak will make the same change.

In appearance the new phonograph with a sound box, tone arm and horn is not unlike ordinary types as shown in Fig. 6. The sound box, tone arm and the horn are designed as parts of a mechanical transmission system and this has led to several new features. For example, the sound box uses a new type of diaphragm.

In order that the vibratory energy shall pass without reflection loss from diaphragm to air chamber, the diaphragm must be very light—.0017″ duralumin is used. But thin duralumin has a metallic rattle when vibrated. To eliminate the rattle, the diaphragm is corrugated all over with such close spacing between corrugations that the flat portions all have natural periods well above the range of speech frequencies. The central two-thirds is corrugated in concentric circles to stiffen it. Between the stiffened central area and the clamped edge tangential corrugations are used to attain four results. First, rattle is eliminated; second, the annulus is made more flexible; third, large amplitude of vibration without distortion is made possible; fourth, neither the flexibility nor the uniformity is destroyed by a slight dishing of the diaphragm in or out and hence solid clamping can be used even with surfaces that are not perfectly true.

Another special feature of the diaphragm is the method of driving it at a number of points by a spider. The central portion of the diaphragm is made to move as a plunger by driving it at six points on a circle near the boundary of the stiffened area. The six legs which attach to the diaphragm are made flexible in order that the spider and the diaphragm shall not vibrate together, their masses adding, but in sequence. That is,

FIG. 7. THE NEW ORTHOPHONIC VICTROLA, WITH MME. GALLI CURCI LISTENING TO THE REPRODUCTION OF HER VOICE.

the spider is another section of the mechanical transmission system.

Another special feature of the sound box is the needle arm bearing. Ordinary knife bearings are not of sufficiently high elasticity as fulcrums and the rotational elasticity as well as the rotational friction is undesirably large. A construction which has been found to meet these requirements is a ball bearing with the steel balls held in position by magnetism.

The other feature which distinguishes the new phonograph is its horn, shown in figure 6. This differs from those ordinarily used in two important respects —it is of logarithmic design, *i.e.*, its area increases by a uniform per cent. for each increment of length and it has a mouth opening adjusted to its rate of taper. The advantage of the logarithmic shape is that for a given volume of horn it gives the greatest effective frequency range of reproduction. The logarithmic shape is continued throughout the whole length of the tone arm, making the tone arm a part of the horn.

With a given rate of taper of horn there is a best mouth opening in order to prevent peaks in the low frequency region of reproduction and this is used. To reproduce frequencies down to 100 cycles with a standard size reproducer diaphragm, a horn about 6 feet long is required. The problem of such a large horn is to a considerable extent that of the size of the cabinet, and a method of folding up the horn has been developed which permits a 6-foot horn to be placed in a standard size phonograph cabinet. It will be noticed that the sound passage is always bent in its thin direction which facilitates sharp turns and compact folding.

WILLIAM BATESON

DIRECTOR OF THE JOHN INNES HORTICULTURAL INSTITUTION NEAR LONDON, DISTINGUISHED FOR HIS RESEARCHES IN GENETICS AND OTHER BIOLOGICAL SUBJECTS. THIS PHOTOGRAPH WAS TAKEN WHEN DR. BATESON CAME TO AMERICA FOUR YEARS AGO AT THE INVITATION OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE TO GIVE AN ADDRESS AT THE TORONTO MEETING. THE ADDRESS ON "EVOLUTIONARY FAITH AND MODERN DOUBTS" ATTRACTED MUCH ATTENTION BECAUSE IT QUESTIONED THE DARWINIAN THEORY AS A SATISFACTORY EXPLANATION OF EVOLUTION AND WAS QUOTED BY MR. BRYAN AND OTHERS AS ADVERSE TO THE DOCTRINE OF EVOLUTION.

THE PROGRESS OF SCIENCE

THE STERLING MEMORIAL LIBRARY OF YALE UNIVERSITY

PLANS for Yale's new monumental Gothic library, designed to house 5,000,000 volumes, and to be erected as a great memorial to the late John W. Sterling, eminent Yale graduate of the Class of 1864, at an estimated cost of $6,000,000, provided by the trustees of the Sterling estate, have been prepared. The Sterling Memorial Library has been designed not only to give immediate facilities for the proper use of Yale's priceless collection of books, accumulated during two centuries and a quarter, but also to meet the university's library needs for the next hundred years.

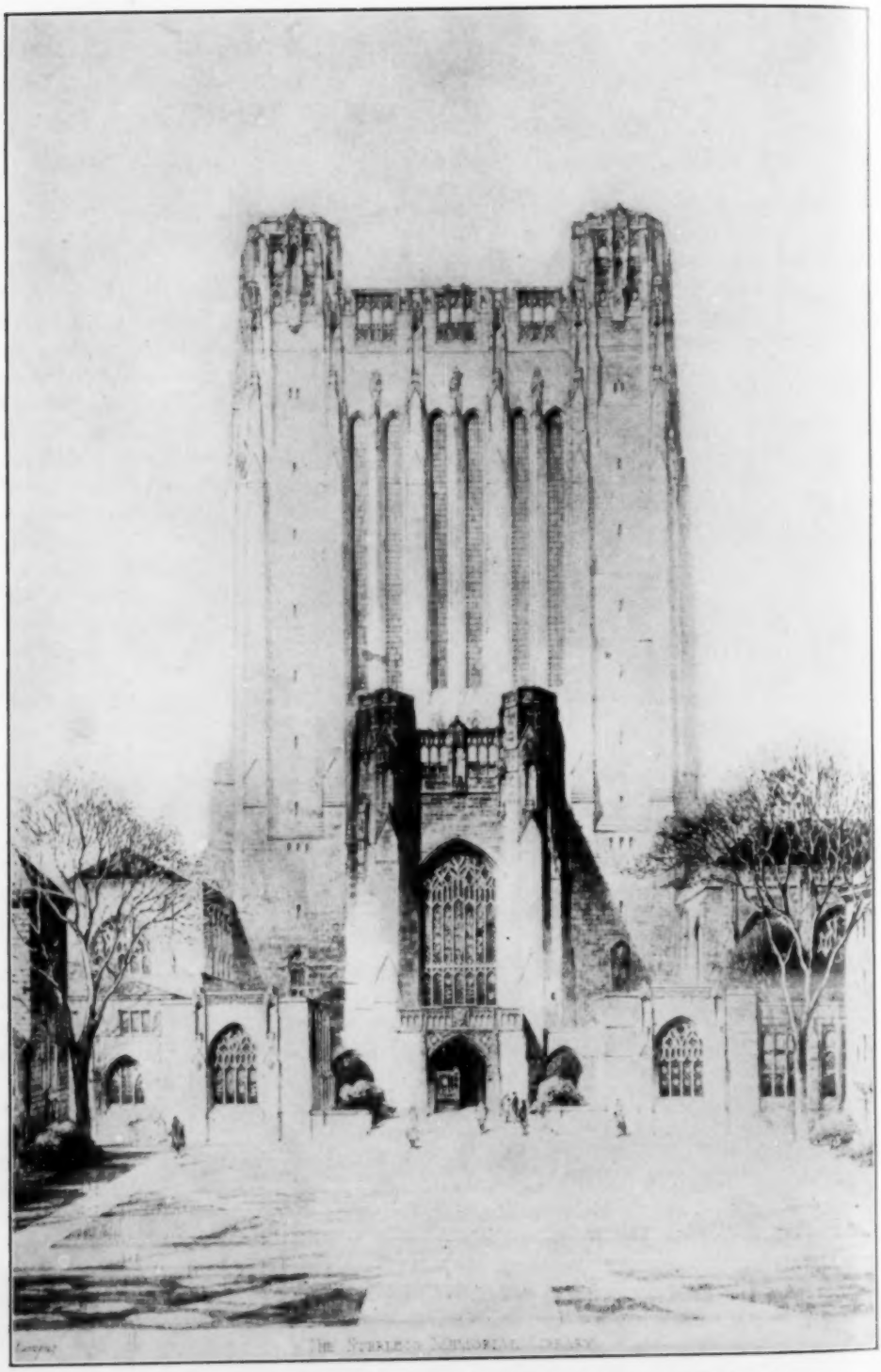
It is expected that the construction of the building will be completed two years from now. It will then probably be the largest and best-planned university library in the world and its special services and conveniences will be unsurpassed. The architect is Mr. James Gamble Rogers, of New York. In outward appearance the new library will harmonize with the Harkness Tower and the Memorial Quadrangle, which are also the work of Mr. Rogers. Andrew Keogh, librarian of Yale University, says that the plans will give the university "a building as efficient as an up-to-date factory and as beautiful as a cathedral." The stipulations given the architect were for good light, flexibility of construction to provide for changing needs, quiet, comfort, quick service for readers, and an inspiring atmosphere.

In the new building 2,000 readers in all may be seated at one time. All the main reading rooms are to be on the street level. When the building is opened there will be available 1,600,000 volumes, besides more than 10,000 periodicals. Accessions to Yale's book collection are now at the rate of 1,000 a week.

One hundred and ninety-two feet high and eighty-two feet square, the dominating feature of the building will be the "book tower," of warm yellow stone and slightly tapering. This will contain twenty-two floors. No shelf will be higher than seven feet, so that all books will be easy of access, and the aisles will be especially wide. Smaller than the book tower, and in front of it, will be an entrance tower. Within is to be the memorial entrance hall, resembling the nave of a great cathedral. Passing through the memorial hall, the future Yale student will find himself in a court, with trees and a fountain and a cloistered walk at one side.

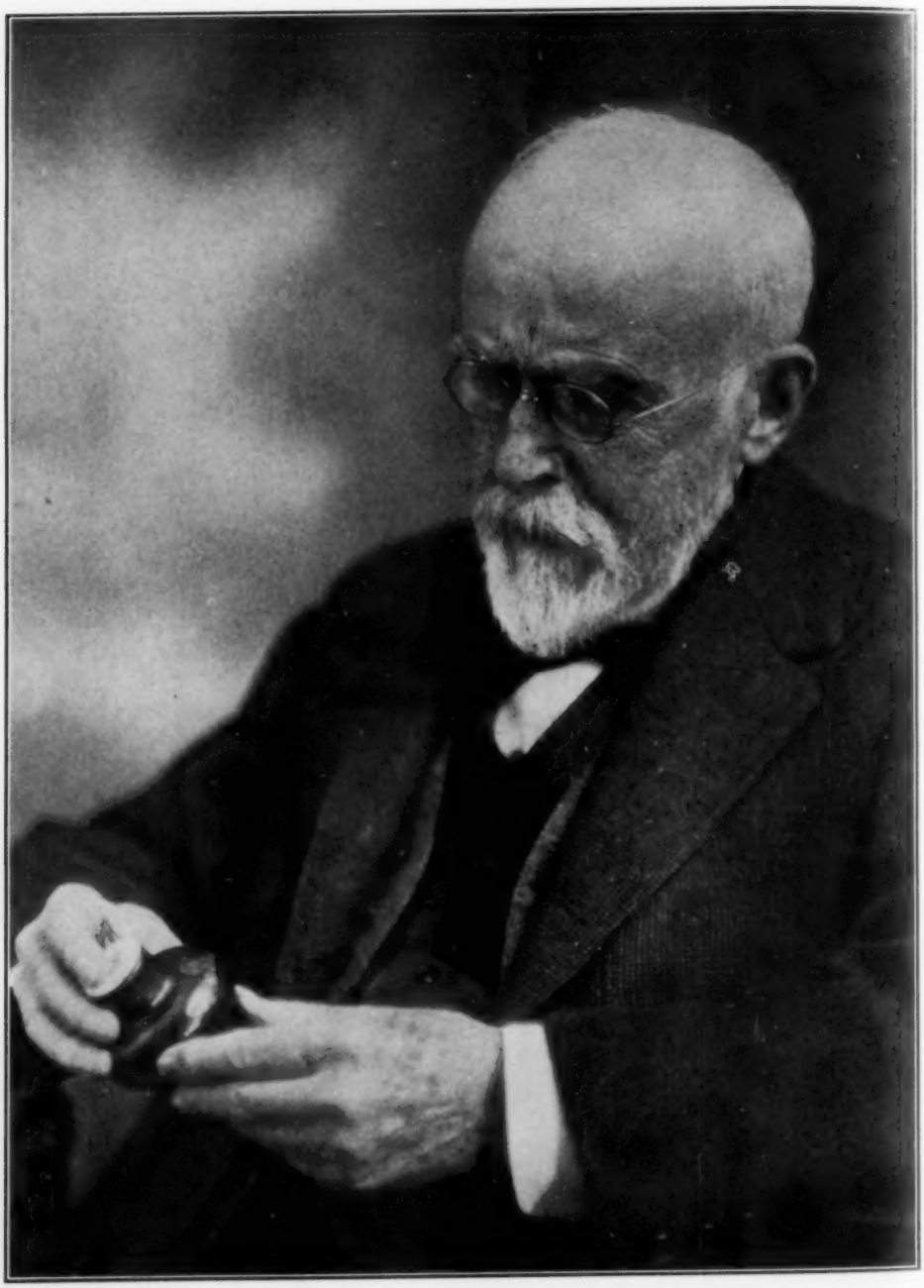
Nearest the main entrance are two reading rooms for undergraduates, one containing reserved books and the other the Linonian and Brothers collections. In the main reading room 15,000 important reference books will be available to any inquirer, and those from adjoining stacks will be brought in by pneumatic carriers. For the creative scholar there will be fifty studies and seminary rooms, and more than 400 stalls in which books and papers may be kept in privacy for a limited time.

A novel convenience for Yale undergraduates will be the so-called non-residents' room in the new library. Students living in neighboring towns or in the outskirts of New Haven need a quiet place where they can work between recitations or at other times. This room will seat 300, and there will be cloak room facilities for all. Reference and text



THE STERLING MEMORIAL LIBRARY OF YALE UNIVERSITY

ENTRANCE HALL TO THE STERLING MEMORIAL LIBRARY



EDWARD SYLVESTER MORSE

books will be available and the unique Andrews Loan Library, from which books may be borrowed for a year at a time, is to be here. The librarian, and his staff, in order to be easily accessible to all who may desire expert assistance, will have their offices on the ground floor, adjoining the entrance hall.

EDWARD SYLVESTER MORSE

PROFESSOR MORSE was born in Portland, Maine, and died at Salem, Mass., on December 20, 1925, in his eighty-eighth year. He retained remarkable physical and intellectual vigor. He played tennis until recently and contributed to THE SCIENTIFIC MONTHLY for October, 1925, an important article on shell mounds. An obituary notice by Professor Morse's life-long friend, Dr. W. H. Dall, has appeared in *Science* and from this we quote.

Like most naturalists Morse early showed an interest in natural history, amassing a notable collection of shells at the age of thirteen, and what is less common, he developed unusual artistic ability. He made for Dr. William Stimpson numerous admirable drawings of living mollusks of the Maine coast. In 1859 he became one of Louis Agassiz's special students at the Museum of Comparative Zoology, where he pursued his studies until 1862 when he published his first paper on brachiopods, a subject to which he later made notable contributions. His first paper to attract particular attention was devoted to some minute landshells of Maine, illustrated by his own drawings.

In 1871 he became professor of comparative anatomy and zoology at Bowdoin, remaining until 1874, and also gave a series of lectures at Harvard. In 1876 he was elected a member of the National Academy of Sciences and the following year went to Japan, led chiefly by the desire of studying the Japanese brachiopoda, in which that region is so rich. He received the appointment of professor of zoology at the University of Tokyo, which he filled with great success, returning in 1880 with large collections and signal honors from the Japanese government. During this period his ready pencil was active in taking notes which later formed the basis of his volume on Japanese homes, and other contributions to our knowledge of the Japanese people for whom he always cherished a profound admiration. At this time too his artistic taste recognized the beauty of the common pottery of Japan, and he made of it the remarkable collection which is one of the treasures of the Boston Museum of Fine Arts, of which he was curator.

On his return to Salem he became director of the Museum of the Peabody Academy of Sciences. His work in this institution made the museum the custodian of the most artistically and scientifically arranged minor collection in the United States, if not in the world.

In 1886 Morse was elected president of the American Association for the Advancement of Science, and in the intervals of activity at Salem lectured acceptably in many parts of the United States.

The salient characteristic of Professor Morse, apart from his devotion to science and love of the beautiful in art, was his boyish enthusiasm which captivated all who knew him. The versatility of his interests was unbounded, his love of fun overflowed at every opportunity; to meet him was to find a welcome. The world was brighter for his presence.

DR. SAMUEL C. LIND AND DR. HUBERT WORK

DR. LIND, ON THE RIGHT, ASSOCIATE DIRECTOR OF THE FIXED NITROGEN RESEARCH LABORATORY, IS EXPLAINING TO DR. WORK HIS EXPERIMENTS ON HELIUM. THE NICHOLS MEDAL IN CHEMISTRY FOR 1925 HAS BEEN AWARDED BY THE NEW YORK SECTION OF THE AMERICAN CHEMICAL SOCIETY TO DR. LIND FOR HIS WORK ON THE CHEMICAL ACTIVATION OF ALPHA PARTICLES.

NITROGEN FROM THE AIR

THE United States Fixed Nitrogen Research Laboratory, of which Dr. F. G. Cottrell is the director and Dr. C. S. Lind the associate director, is actively engaged in studies of methods of obtaining nitrogen from the air, which can utilize the vast energy of Muscle Shoals, which is still under the control of the United States government. An article by Dr. Cottrell in THE SCIENTIFIC MONTHLY for September, 1925, describes these methods. A recent bulletin of *Science Service* states that American crops and factories use nearly $75,000,000 worth of nitrogen in one form or another each year, and over $50,000,000 of this comes from abroad, chiefly from Chile. Other kinds come as fertilizer from factory wastes or as ammonia in liquors from coal distillation in the making of gas coke. The rest is made synthetically from the nitrogen in the air by chemical means.

In 1925 the world used 857,000 tons of the element nitrogen, exclusive of that occurring in animal products or foods. Of this amount 44 per cent. comprised the nitrogen in the output of Chile saltpeter, and 56 per cent. was fixed nitrogen.

A monopoly of nitrate producers controls practically the entire output of the Chilean fields. The government of Chile is a party to the monopoly and puts a tax of $12.34 on every ton of nitrate that leaves the country. At present, the price of the nitrate, artificially boosted by the tax, sets the standard for all synthetic nitrates and fertilizers.

It is believed that when the methods for getting nitrogen from the air are further improved and more commonly used, synthetic nitrogen products will turn the tables on the Chilean fields. Recently discovered means of getting nitrogen from the air where it exists in unlimited quantities and in an elusive form, have become of vital importance in peace and war. By these means Germany freed herself from Chile before the war, and the United States might do the same.

As a result of nitrogen fixation it is estimated that 56 per cent. of the world's supply of inorganic nitrogen came out of the air in 1925. Before the war only 10 per cent. was got in that way. The plentiful supply of nitrogen which is in the air and there for the taking, may make it possible for agriculture of the future to meet the demands of the fast-growing population of the world, which is disturbing the sleep of many an earnest economist. There is almost unlimited room for improvement in agriculture. The Department of Agriculture points out that in 1925, out of the forty odd millions of acres planted in cotton, only about 36 per cent. are fertilized.

"What is done with the nitrogen problem in the next ten years will go far to determine American standards of living," according to a statement of Dr. Harry A. Curtis, former chief of the nitrate division of the U. S. Department of Commerce. "Unless relatively cheap fixed nitrogen can be supplied to agriculture each acre will produce smaller crops while our population will continue to get larger."

Although the processes for getting nitrogen from the air are less than twenty years old they already give the world each year an amount greater than that shipped out of the Chilean fields. There are many possible ways of hooking up the obdurate atmospheric nitrogen with materials on earth, but only three of these ways are actually used.

The simplest of these is the electric arc process. Nitrogen is induced to combine with oxygen by the powerful stimulant of electricity. The nitric oxide formed is passed through huge absorption towers where it reacts with water and more oxygen to form dilute nitric acid. The process has been success-

ful in Norway, but the exceedingly high electric power requirement has prevented its use in most other countries.

In the cyanamide process, which was first used in Italy, nitrogen is trapped as it passes over finely powdered calcium carbide heated to about 1,000 degrees. It becomes chemically fixed into solid calcium cyanamide which can be easily changed to ammonia gas or nitric acid. The raw materials needed for making the calcium carbide are coal and limestone, and the energy required is only about one fourth that needed for the arc process. It was found that calcium cyanamide could be put directly into the soil as a fertilizer. This stimulated production, and in 1913 there were already nine producing countries making 172,000 tons of the substance. The production is about four times as great to-day.

The synthetic ammonia process, the newest of the three methods of nitrogen fixation, was not known outside of Germany when the world war began. To-day, however, there are many processes based on the same principle. The pioneer Haber process was worked out mostly by Fritz Haber in Germany between 1905 and 1908. The principle involved has been called the most far-reaching accomplishment of chemical engineering. A properly proportioned mixture of nitrogen and hydrogen gas is passed over a catalyst, a substance that by some seemingly magic influence can make two unwilling elements react chemically toward one another. The combination forms ammonia. Heat is produced, and not absorbed, during this reaction and the more the temperature is kept down and the pressure up the more ammonia is evolved.

A CHILD'S ANATOMY

From *Punch*

Child (to doctor who is making long and careful examination of her spine).—"IF YOU 'RE TRYING TO FIND MY TUMMY IT 'S ON THE OTHER SIDE."